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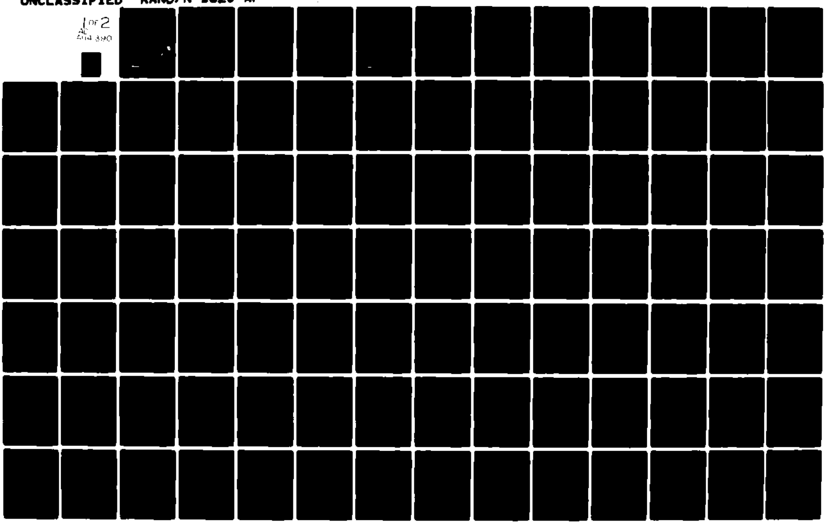

A RAND NOTE

TSAR USER'S MANUAL: VOLUME I--PROGRAM FEATURES, LOGIC, AND INTERACTIONS

Donald E. Emerson

February 1982

N-1820-AF

Prepared For

The United States Air Force

Rand
SANTA MONICA, CA. 90406

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This Note is one of five documents that collectively describe the TSAR and TSARINA computer models developed to assess the effect of air attacks on the sortie generation capabilities of air bases. The Theater Simulation of Airbase Resources (TSAR) model provides an analytic context within which a variety of airbase improvements may be tested. The present Note provides a full description of the logic used in the TSAR model, as well as an understanding of the interrelations among the many elements of the logic for programmers interested in modifying and extending the exisiting program logic.

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PREFACE

This Note is one of five documents that collectively describe the TSAR and TSARINA computer models developed at The Rand Corporation to assess the effect of air attacks on the sortie generation capabilities of air bases. This development was carried out under the Project AIR FORCE Resource Management Program project entitled, "Strategies To Improve Sortie Production in a Dynamic Wartime Environment."

The Theater Simulation of Airbase Resources (TSAR) model provides an analytic context within which a variety of airbase improvements may be tested. New passive defenses, new maintenance doctrine, modified manning levels, improved base repair and recovery capabilities, increased stock levels for parts and equipment, etc., as well as concepts for improved theater-wide resource management, all can be examined for their effect on aircraft sortie generation. These models have been briefed to several Air Force organizations during the development process.

The present Note provides a full description of the logic used in the TSAR model, as well as an understanding of the interrelations among the many elements of the logic for programmers interested in modifying and extending the existing program logic. The companion documents include:

R-2584-AF — An Introduction to the TSAR Simulation Program: Model Features and Logic

N-1460-AF — TSARINA--User's Guide to a Computer Model for Damage Assessment of Complex Airbase Targets

N-1821-AF — TSAR User's Manual: Vol. II--Data Input, Program Operation and Redimensioning, and Sample Problem

N-1822-AF   TSAR User's Manual: Vol. III--Variable and Array Definitions, and Other Program Aids for the User

Other documents are planned that will discuss the problems associated with data acquisition for these models and will present the procedures currently under development at Rand to assist in solving those problems.

ACKNOWLEDGMENTS

The development of the TSAR computer model demanded uninterrupted concentration over an extended period. My debts to the Air Force and to Rand management are obvious. Not so obvious are the debts owed my most understanding family, who endured my total absorption in TSAR's development for over three years.

Among my colleagues at Rand, I would particularly like to thank Louis Wegner and Michael Poindexter for their many helpful ideas and suggestions for dealing with a variety of programming problems, and Major John Halliday and Milton Kamins for their ideas that have been incorporated into TSAR logic and for their careful work in creating the data bases that were used for TSAR development.

CONTENTS

GLOSSARY

AGE	Aerospace ground equipment and other equipment used for carrying out various tasks
AIS	Avionics Intermediate Shops; special test equipment used for repairing avionic LRUs and SRUs.
BLSS	Base-level self sufficiency stock of aircraft spare parts
CAP	Combat Air Patrol
CAS	Close Air Support
CILC	Centralized Intermediate Logistics Concept
CIRF	Centralized Intermediate Repair Facility
COB	Collocated Operating Base
COMO	Combat Oriented Maintenance Organization
CONUS	Continental United States
FRAG	Framentary order that specifies flight requirements
LCOM	Logistics Composite Model
LRU	Line replaceable unit; an aircraft spare part
MOB	Main Operating Base
NMCS	Not mission capable because of lack of spare parts
NORS	Not operationally ready because of lack of spare parts; same as NMCS
NRTS	Not reparable this station
OST	Order and ship time
POL	Petroleum, oils and lubricants; often used as an abbreviation for aircraft fuel
POS	Peacetime operating stock; an organization's stock of aircraft spare parts for aircraft maintenance in peacetime
RAM	Rapid area maintenance; special mobile teams used for repairing aircraft battle damage
RR	Flight line maintenance that removes and replaces malfunctioning aircraft parts with serviceable components

RRR	Flight line maintenance that removes, repairs, and replaces aircraft spare parts (actually, usually removes and replaces with a serviceable unit, and then repairs malfunctioning unit)
RRR	Rapid runway repair
SAMSOM	Support Availability Multi-System Operations Model
SCL	Standard combat load that designates the mission dependent munitions to be loaded
SRU	Shop replaceable unit; a component of an LRU
TRAP	Tanks, racks, adaptors and pylons
TSAR	Theater Simulation of Airbase Resources
TSARINA	TSAR Inputs using AIDA
WRM	War Reserve Materiel
WRSK	Wartime readiness spares kit

I. SUMMARY OF TSAR CAPABILITIES

TSAR simulates a system of interdependent theater airbases, supported by shipments from CONUS and by intra-theater transportation, communication, and resource management systems. The simulation, by capturing the interdependencies among eleven classes of resources, will permit decisionmakers to examine the implications of a broad spectrum of possible improvements, in terms of their effect upon the sortie generation capabilities of a system of air bases. The simulation also allows examination of the effects of damage inflicted by enemy air base attacks and by efforts to restore operations.

The classes of resources treated in TSAR are (1) the aircraft, (2) the aircrews, (3) the ground personnel, (4) support equipment (AGE), (5) aircraft parts, (6) aircraft shelters, (7) munitions, (8) TRAP, (9) POL, (10) building materials, and (11) airbase facilities. Many different types of each class of resource may be distinguished. When included in the simulation, either the user will specify initial parts stocks or TSAR will initialize the parts data according to standard algorithms for POS, BLSS, and WRSK and will also initialize the stock location in the depot pipeline.

TSAR is a Monte Carlo discrete-event simulation model that analyzes the interrelations among available resources and the capability of the airbases to generate aircraft sorties in a dynamic, rapidly evolving wartime environment. On-equipment maintenance tasks, parts and equipment repair jobs, munitions assembly, and facilities repair tasks are simulated at each of several airbases. A broad range of policy

options that would increase initial resources, accelerate task completion, or improve theater resource utilization may be assessed using TSAR. Provisions also are included that provide the user a capability to assess dynamic variations in key management policies.

TSAR is readily adaptable to initial conditions encompassing a broad range of complexity. When specific features are not needed for the examination of a particular issue, they simply need not be used. Thus, TSAR permits one to represent either a single base, a set of independent airbases, or a set of interdependent airbases, without any adjustment or modification of the program. Similarly, the user may not wish to examine the effects of airbase attacks, or may wish to ignore the possible restraints imposed by shortages of aircrews, shelters, ground personnel, equipment, aircraft parts, munitions, TRAP and/or fuel. TSAR adapts automatically to all such problem representations.

TSAR provides potential users a means with which a rich variety of potential improvements for theater airbases may be tested in a common context. New passive defenses, new maintenance doctrine, modified manning levels, increased stock levels for parts and equipment (etc.) as well as several concepts for theater-wide resource management can be assessed with TSAR by comparing how such improvements affect the system's capabilities for generating sorties.

An important objective in the original design formulation was to achieve a sufficiently high speed of operation that the extensive (often trial and error) sequence of runs so frequently necessary in research and analysis would be economically practical. Adaptation of existing models (e.g., LCOM, SAMSOM) was rejected because modifications would

have been extensive and costs prohibitive for problems of the size that were contemplated. The TSAR program is written in the widely available FORTRAN language and achieves a substantially higher speed by virtue of more efficient processing, and by taking advantage of the recent dramatic increases in the size of the core storage of modern computers. In its current formulation, TSAR makes no intermediate use of auxiliary high-speed storage units (e.g., disks, tapes) except for storing the initial conditions for multiple trials.

In TSAR, specified numbers of aircraft of various types can be assigned to each airbase. The aircraft of a given type at any airbase may be supported by a common pool of resources (personnel and equipment), or, as in the COMO concept, the aircraft may be organized into two or three sub-groups (squadrons) each supported by its own set of resources. The aircraft are launched on sorties in response to a set of user-supplied sortie demands, differentiated by base, aircraft type, mission and priority; if a base is not specified the sortie demands are allocated to the base best able to generate the necessary sorties. Flights may be scheduled or scrambled on demand using aircraft that have been placed on alert.

Aircraft may be lost on a combat mission, or, when an aircraft returns it may be damaged, still have munitions, and have several unscheduled maintenance task requirements. These unscheduled maintenance tasks are normally accomplished at the aircraft's operating base, but an aircraft may be ferried to a rear base for specific maintenance tasks. When aircraft are lost, a replacement may be ordered from CONUS, or, if aircraft are set aside in the theater as fillers,

these are used to provide rapid replacements for lost aircraft, and, if specified, for aircraft ferried to the rear for maintenance. When filler aircraft are used to replace losses, a replacement for the filler force is ordered from CONUS, if such resources are available.

When an airbase runway has been closed because of an airbase attack, aircraft scheduled to land are diverted to other bases, preferably to one that normally operates the same type of aircraft. If base sortie generation capabilities are assessed daily (an option), the base best able to support the aircraft is selected. During the period that a runway remains closed, that airbase's sortie demands are allocated to functioning airbases with the appropriate type of aircraft either in proportion to the aircraft available or, if base capabilities are assessed daily, in proportion to the sortie generation capabilities of the bases. When a runway has been reopened, that base's aircraft recover at their parent base on completion of their next combat sortie, if base sortie generation capabilities are not assessed or, if they are, when their parent base's sortie-generation capability per-available-aircraft is within a specified percentage of that at the temporary base.

The next assignment for each aircraft is selected tentatively when it lands; that selection takes into account the known demand on that base for sorties and the projected capability of the aircraft at that base to meet those demands. The selection also takes into account which of that aircraft's unscheduled maintenance tasks would need to be accomplished for the different missions, and when that particular aircraft could probably be readied for the different missions. All tasks that are not essential for the tentative mission assignment may be

deferred and the available resources concentrated on required tasks. If aircraft are eventually found to be unneeded for the mission for which they were readied, they are reassigned and reconfigured for a more appropriate mission.

On-equipment maintenance tasks may require a number of people, specialized equipment, and spare parts; each task is either a single set of such requirements--i.e., a simple task--or a network of tasks, each with its own demand for personnel, equipment, and parts. When resources are limited, those aircraft most likely to be readied first (given sufficient resources) may be given priority. The basic input data that govern the probabilities for unscheduled maintenance tasks (other than battle damage repairs) may be used directly for the simulation or varied statistically to reflect unexpected differences between planned levels and "actual" wartime experience. Futhermore these task probabilities--i.e., the breakrates--may either have a fixed rate or be varied daily by shop and aircraft type as a function of achieved sortie rate, or other user specified adjustment.

If a required part is not available, (1) the broken one that is removed may be repaired on base, (2) the appropriate part may be cannibalized from another aircraft, (3) a part may be obtained by lateral resupply from a specified subset of bases, or (4) the part may be ordered from a central source within the theater. When a part may not be repaired on base (is NRTS) it may be sent to a neighboring base or to a centralized facility in the theater designated to perform intermediate maintenance--i.e., a CIRF. When parts may not be repaired within the theater, a replacement may be requested from a depot in

CONUS, when specified by the user. Parts may either be a simple part that with some probability can be repaired on base, or an LRU that has a defective SRU. For simple parts, either one specific procedure is required for repair, or one procedure is selected at random from two or more repair procedures. For LRUs the resource requirements to diagnose and replace the faulty SRU are specified separately for each SRU. Faulty SRUs, withdrawn from an LRU, may themselves be repaired on-base, or NRTSed to another location for repair.

The various types of support equipment used in on-equipment and off-equipment jobs, munitions assembly and loading tasks, and by base civil engineers, are themselves subject to malfunction and repair. As with spare parts, equipment repair may follow a specific procedure or may be accomplished by one of several procedures selected at random. The special complexities of *full and partial-mission-capability* of AIS test equipments used to repair LRUs and SRUs for late-model aircraft may also be simulated.

Each maintenance task, parts repair job, and equipment repair job is accomplished by the personnel and equipment associated with a particular work center or shop. The user may group the resources and tasks into up to 25 different "shops" exclusive of those associated with the scheduled preflight maintenance tasks. Since each shop may be assigned several different types of personnel and equipment, those engaged in on-equipment and off-equipment tasks may be the same or different depending upon how the user wishes to define the base's maintenance policies.

The user is given substantial flexibility in defining the rules by which aircraft maintenance tasks are processed. He may permit the activities of certain groups of shops to proceed simultaneously or may require that the activities of several such groups of shops proceed in a specified order. He also may control these prescriptions for simultaneous and sequential operations, separately for each aircraft type at each base. Furthermore, for those groups of shops that are permitted to proceed simultaneously, certain exceptions may be specified in the form of lists of activities that are incompatible with each particular task. These features permit alternate maintenance operating doctrine to be simulated and to be examined for their influence on sortie generation capabilities. Work speed-up and other procedures to shorten on-equipment, preflight, and off-equipment activities also may be specified.

Scheduled preflight tasks are also associated with the shop structure. These tasks involve aircraft refueling and the loading of both basic defensive munitions and mission-dependent munitions. The likelihood that the basic munitions and the mission-dependent munitions are retained from the previous sortie can be specified independently for the two classes of munitions. After mission assignment, aircraft configuration is checked and, if necessary, the aircraft is reconfigured; this may involve one or two separate tasks, each of which may require TRAP, personnel, and equipment. The loading of the mission-dependent munitions also may involve one or two separate tasks, each with its distinct requirements.

When munitions assembly tasks are simulated, munitions demands are projected periodically to define which types of munitions need to be assembled. Such jobs may require both personnel and equipment, much like other tasks that are simulated in TSAR. When munitions assembly is simulated, initial stocks of munitions, as well as munitions shipments, are distinquished as to whether the munitions are assembled or not.

Several features permit the user to simulate various "work-around" procedures that can alleviate resource constraints. One such feature permits the user to specify alternative resource requirements for any unscheduled on-equipment task, parts repair job, equipment repair job, weapons assembly task or civil engineering job; one might, for example, specify that a three man crew could do a normal four-man job in 50 percent more time. Similarly, when TRAP or munitions shortages do not permit the normal, or preferred, munitions to be loaded for a mission, several alternative loadings may be specified. A third "work-around" feature permits the user to designate that certain types of personnel have been cross-trained and that they may replace or assist certain other specialists. This personnel substitutability feature is operative only for specified bases and on specified on-equipment tasks, munitions assembly tasks, and civil engineering jobs.

The effects of damage due to airbase attacks may be simulated. The user specifies the time and location of the attacks, the repair requirements for the runways and taxiways, and the percentage damage suffered by the various resources on the basis of other calculations. (A customized modification of the AIDA--Airbase Damage Assessment--

computer model has been developed[1] that generates and stores airbase damage data in the exact format required by TSAR.) When aircraft or facilities are destroyed, some portion of the personnel, equipment, and parts at these locations also may be lost. Aircraft are kept in shelters when sufficient shelters are available, but the aircraft may be partially exposed when certain shop operations are underway at the time of airbase attack; different loss rates are applied in each case. Alert aircraft may be given priority in shelter assignment, and the damage to these aircraft may be distinguished from that for other aircraft. Aircraft in excess of those that may be placed in a shelter sustain a third distinct loss rate. After TSAR has decremented the various resources to the extent implied by the damage data, the surviving personnel are reorganized into night and day shifts. After a user-stipulated delay to roughly account for the disruptive effects of the attack, the maintenance personnel resume their activities, unless their facility is required and has been damaged.

Replacement resources (i.e., aircraft, pilots, personnel, parts, munitions, TRAP, and building materials) may be ordered from CONUS when losses are sustained. The number of resources that are available for replacing losses may be specified for each type of resource, and the time required to replace the loss may be specified independently for each class of resource.

After an airbase attack, civil engineering personnel, equipment, and building materials may be allocated according to a priority system

[1] D. E. Emerson, _TSARINA--User's Guide to a Computer Model for Damage Assessment of Complex Airbase Targets_, The Rand Corporation, N-1460-AF, August 1980.

to commence the repair or reconstruction of the damaged facilities. Operation of those facilities is resumed when they once again are functional.

In addition to simulating a set of airbases, the user also may specify the existence of a theater reserve of filler aircraft, a centralized theater distribution center, or a centralized theater repair facility at which some or all intermediate maintenance is conducted. The filler aircraft can, at the user's option, be used to replace aircraft losses or to replace aircraft that have been withdrawn to a rear base for maintenance, as well as losses. When additional aircraft resources are specified as available in CONUS, they supplement the filler force. The filler aircraft are managed so as to maintain the inventories at the operating bases to the extent possible.

The centralized distribution facility can receive spare parts from CONUS and either retain them until demanded by a base or transship)some or all) to the base with the earliest projected requirement. Such a facility can also be used to direct the lateral shipment of parts and other resources from one base to another. A theater parts repair facility, sometimes referred to as a CIRF, is assigned maintenance personnel, equipment, and spare parts (LRUs and SRUs). Parts are shipped to and from the CIRF from the operating bases and are processed in the manner prescribed by the user's choice of which theater management rules are to govern these operations.

The simplest rules for CIRF operation prescribe that faulty parts are repaired in the order in which they arrive, and that they are returned to the sender. The user may also invoke a variety of more

complex management algorithms, not only for selecting what to repair and how to dispose of parts when they have been repaired, but for reallocating personnel, equipment, and parts among the several operating bases. Repair priorities can be based on existing and projected demands and on the relative essentiality of parts for the various missions. Shipment priorities are related to the current and projected demands, on-base reparables and enroute serviceables. When central stocks are insufficient to meet a base's demand, another base can be directed to ship the required part, if both the requesting base and the donor base meet certain conditions relative to the importance of the demand and the availability of stock.

Daily estimates can be prepared (an option) of each base's capabilities for generating different kinds of missions with different types of aircraft. These estimates provide the basis for various aircraft management decisions. One application is in selecting which base is to be assigned the sortie demands for which no base has been specified. These data can also be used for assignment decisions when aircraft must be diverted and when aircraft are transferred from base to base to balance maintenance workloads.

The theater-wide management of the various resources is supported by a user-specified scheduled transportation system that may be subjected to delays, cancellations and losses. TSAR also permits the user to represent a theater-wide reporting system that can be used to provide the central management authority with periodic resource status reports from the several operating bases; these reports may be delayed, incomplete, or lost.

When these transportation and communication systems are coupled with the sets of rules for distributing and redistributing resources among the operating bases, various concepts of theater resource management may be represented and examined in the context of realistic transportation and communication imperfections. In its current formulation TSAR already includes certain alternatives for the theater management rules and has been designed to permit additions or modifications to be readily accommodated.

TSAR naturally has limitations and omissions that will inconvenience some potential users. The more obvious limitations derive from the manner in which the problem was bounded in designing TSAR. Some users will be bothered that TSAR treats friendly sorties simply as delays during which time the aircraft are not present at an airbase; others will wish that active airbase defenses had been included as an integral part of the simulation, rather than being required to consider active defense tradeoffs externally to TSAR analysis; and still others will find that these tools would be more useful if the production oriented, batch processing of spare parts, as they are handled at depots, also were modeled. The ever increasing importance of treating chemical warfare in military analyses suggests another significant omission in the current TSAR/TSARINA design. Other perhaps less obvious restrictions derive from the absence of time as a variable in TSARINA, and the absence of relative locations in TSAR.

Each of these design limitations could be a serious obstacle for some potential users, but none of these bounds was chosen casually or accidentally. All problems must be bounded, and I believe my choice of

boundaries need not inhibit a wide variety of significant and useful analyses. Furthermore, it would be fairly easy--conceptually--to substantially extend or eliminate these boundaries since TSAR's existing data structure is sufficiently detailed to be compatible with such additions. Indeed, additions are currently being tested that will permit examination of chemical attacks. But even though such additions are conceptually easy, most would entail difficult design and programming efforts and would further increase TSAR's execution time and expand its data collection problems.

The last of the limitations that should be highlighted is TSAR's data input requirements. As one elects to include more and more of the real world considerations that TSAR permits the user to include, these requirements become substantial. That is not a property of TSAR, but of the richness of the user's problem definition; any approach to dealing with his problem at a comparable level of detail would require equivalent information. TSAR's main contribution to this dilemma is that it will function comfortably at many levels of detail and the user may quite simply select or reject most of its features and the related data requirements. One important benefit of this flexibility is that analysts can test the potential sensitivity of their results for a particular effect for which the data would be difficult or costly to secure, using invented data that spans a reasonable range of uncertainty. If his results are reasonably insensitive to that variation he has a solid argument for neglecting the effect; if they are sensitive he has a compelling argument for mounting the requisite effort to secure the needed data.

II. TSAR DOCUMENTATION

TSAR documentation has been designed with four classes of readers in mind:

* Those seeking only a broad overview of TSAR's capabilities,
* Those without a background in programming who seek a full understanding of the logic in the TSAR simulation,
* Those responsible for preparing input materials and for operating TSAR, and
* Those interested in modifying and extending the existing program logic or trying to understand apparent errors.

Only Sections I through III of the introductory volume[1] will be of interest to the first group, but that entire volume is appropriate for the second. The three volume User's Manual is provided for the last two groups.

The TSAR User's Manual is built around four main bodies of mutually supporting explanatory materials. These volumes are intended primarily for those responsible for operating TSAR, and for programmers who wish to extend the program logic, or are seeking to understand an apparent error. This first volume of the User's Manual provides a succinct but complete discussion of the processing logic involved in the twelve major subsets of tasks; eight constitute the simulation proper and the other four deal primarily with housekeeping chores; these twelve are treated

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[1] D. E. Emerson, An Introduction to the TSAR Simulation Program: Model Features and Logic, The Rand Corporation, R-2584-AF, February 1982.

in order in Sections IV through XV. The second major body of materials are the discussions of the input requirements, procedures, and formats that are found in Volume II; these detailed discussions provide the only complete explanations for some of the numerous control options available with TSAR and must be considered mandatory reading for any one planning to operate TSAR. The third body of materials is the complete listings and explanations of the very substantial data base that is maintained within the simulation; these are located in Volume III. The program, together with its extensive comments, provides the fourth body of materials. The discussions in subroutines INIT, CONTRL, READFT, IPARTS, DOSHIP, BOMB, and REORGN are particularly extensive and will prove helpful in tailoring TSAR for specific applications; any residual questions regarding TSAR logic will probably be answerable with the liberal explanatory comments included throughout all major TSAR subroutines.

The way these materials can be best used undoubtedly will vary widely. If the user's immediate concern is to decide on TSAR's adequacy for installation at his organization, his reading should probably begin with the introductory volume. If that decision has been made and the problem is to apply TSAR, the user might best begin with a cursory reading of the first sections of the introductory volume, or this volume, and then turn to the discussion of the input procedures for the sample problem in Section XX of Volume II. As the user begins to understand how TSAR is to be used for his problem and starts to develop the needed input data, he will want to refer to the detailed discussions of the data input procedures in Sections XVIII and XIX. When questions

arise as to how TSAR will deal with particular aspects of the problem, the user can consult the appropriate section in this volume.

As the user builds his first TSAR data base, he will be well advised to hold down the number of aircraft for his trial problem; that number can easily be increased later. This will minimize the time and trouble to locate, understand, and eliminate the errors that will inevitably creep into a user's first data base. One to three airbases, with six to eight aircraft per base, can provide quite useful and very rapid hands-on experience. And as that first trial problem begins to provide output, the user will want to refer to Section XXI where the output formats are explained with illustrations from the sample problem.

When all appears to be behaving logically for a simple trial problem, it will be time to explore some of the more complex control variables that the user may elect to apply in his problem; only when those are mastered will it be appropriate to increase the size of his aircraft fleet.

III. STRUCTURAL OVERVIEW

The complete TSAR simulation involves many types of events and many classes of resources as well as a considerable variety of output information. To fully understand the simulation, one must understand what the events are, how decisions are made as to when they begin and when they end, and what resources are required. Of particular importance are the internally generated events that must be defined, initiated, and concluded, and that sometimes must wait or be interrupted. On-equipment aircraft maintenance tasks, off-equipment parts repair jobs, equipment repair jobs, munitions assembly jobs, and civil engineering reconstruction jobs generate such events.

In broadest terms the TSAR simulation can be divided into three phases; the input and initialization phase, the simulation, and the output phase. The MAIN executive routine initiates these computational phases and, assisted by the TRIALS subroutine, controls processing for the specified number of trials as suggested in Fig. 1. Each of the three phases uses various subroutines to carry out the required computations.

Figure 2 indicates the interactions among the subroutines that are used to input data and to initialize the various data arrays according to user-specified instructions. Subroutine INIT zeros out the storage space for the named common statements and then subroutine INPUT enters data that describe the resource requirements for the different types of tasks, mission characteristics of the aircraft, on-base resource stock levels, descriptions of the intra-theater transportation and

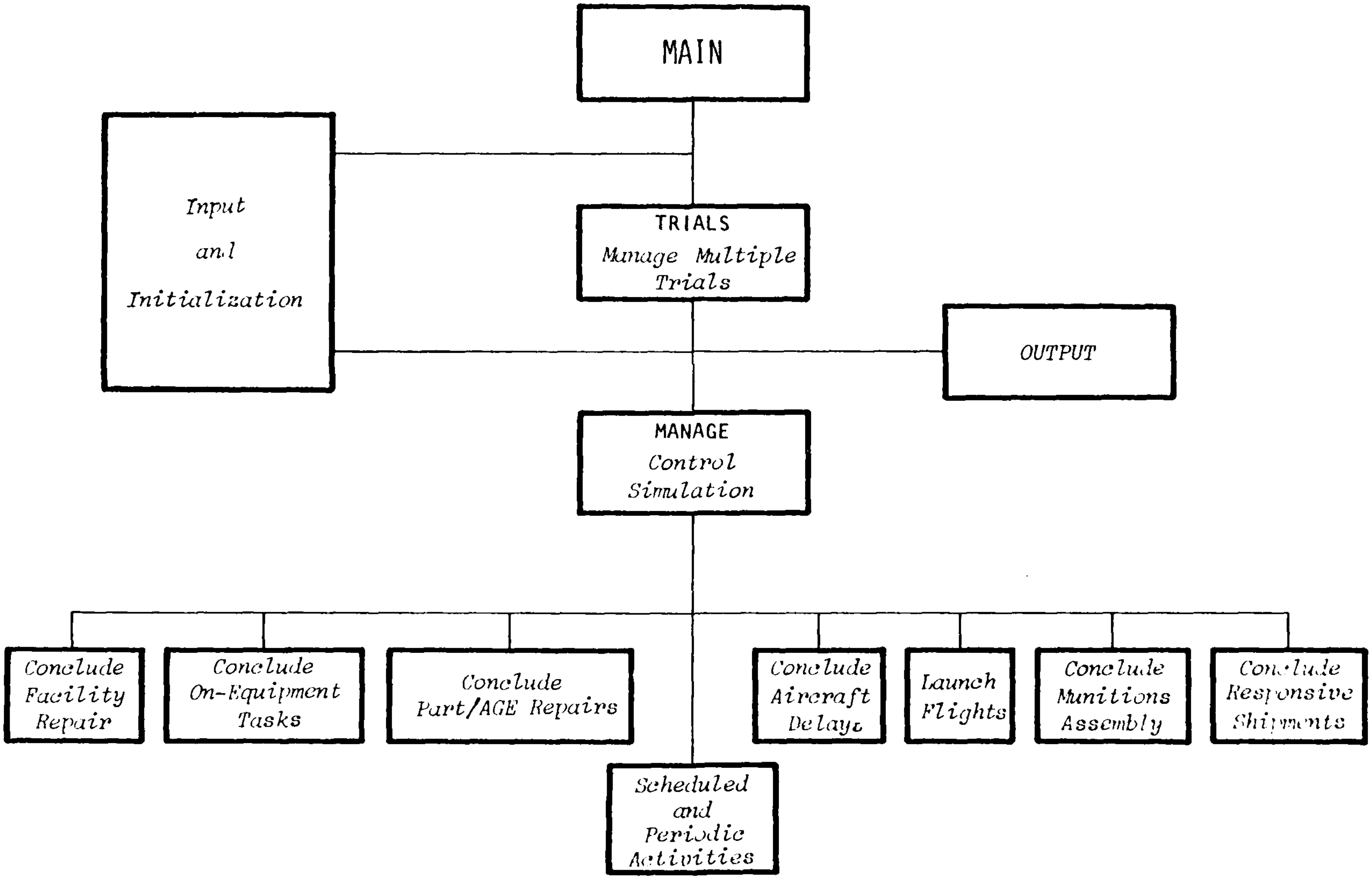


Fig. 1 -- BASIC STRUCTURE OF THE TSAR SIMULATION

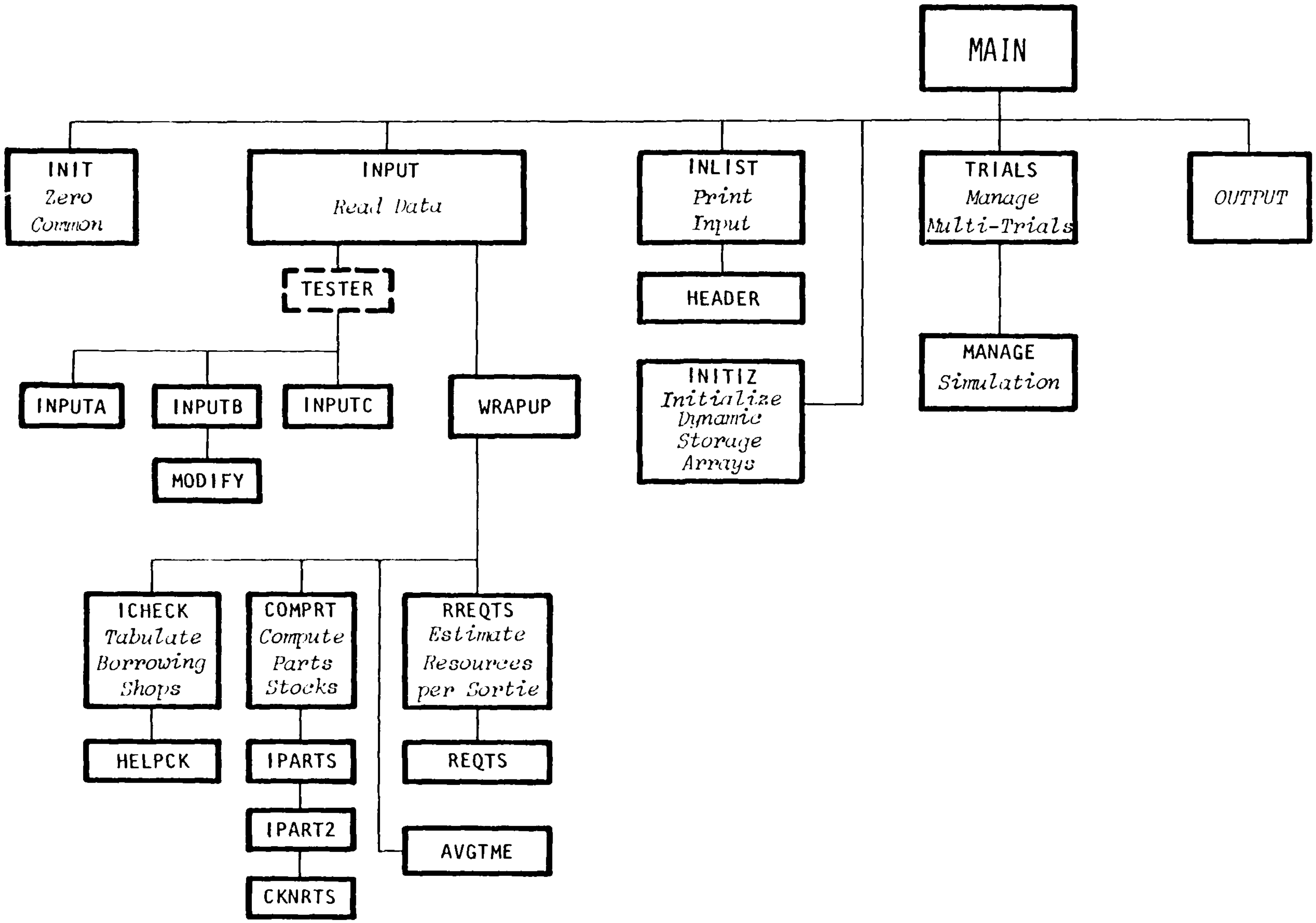


Fig. 2 -- TSAR INPUT AND INITIALIZATION

communication systems, and so on. Subroutine WRAPUP then manages a series of computations that generate a variety of derivative data used during the simulation. After subroutine INLIST and INITIZ have listed key input data and initialized the dynamic storage arrays, subroutine TRIALS takes over control until the simulation is completed and the final outputs are prepared and printed. Before transferring control to subroutine MANAGE, which manages the simulation proper, subroutine TRIALS establishes the user-specified initial conditions of outstanding on- and off-equipment work, and reads the first of the flight demand data. Then, as suggested in Fig. 1, control is passed to subroutine MANAGE, which carrys out each simulated event in its appropriate time sequence.

Basically the TSAR computer simulation processes one event after another in the order in which the events occur in simulated time, initiating whatever subsequent actions are dictated by the prescribed behavior logic for each type of event. Each of the main tasks indicated in Fig. 1 is performed by a cluster of subroutines supported by a set of storage arrays. Although there is substantial interaction between these tasks and their subroutine clusters, much of the discussion in the following sections will examine one major task at a time, only noting the interactions in passing.

The general organization of these subroutine clusters is indicated in Figs. 3 and 4. As can be seen, each subroutine cluster is used to control one of the irregularly reoccurring types of airbase activities; one set is used to launch aircraft and another is used to process aircraft when they are recovered; others are used to release resources

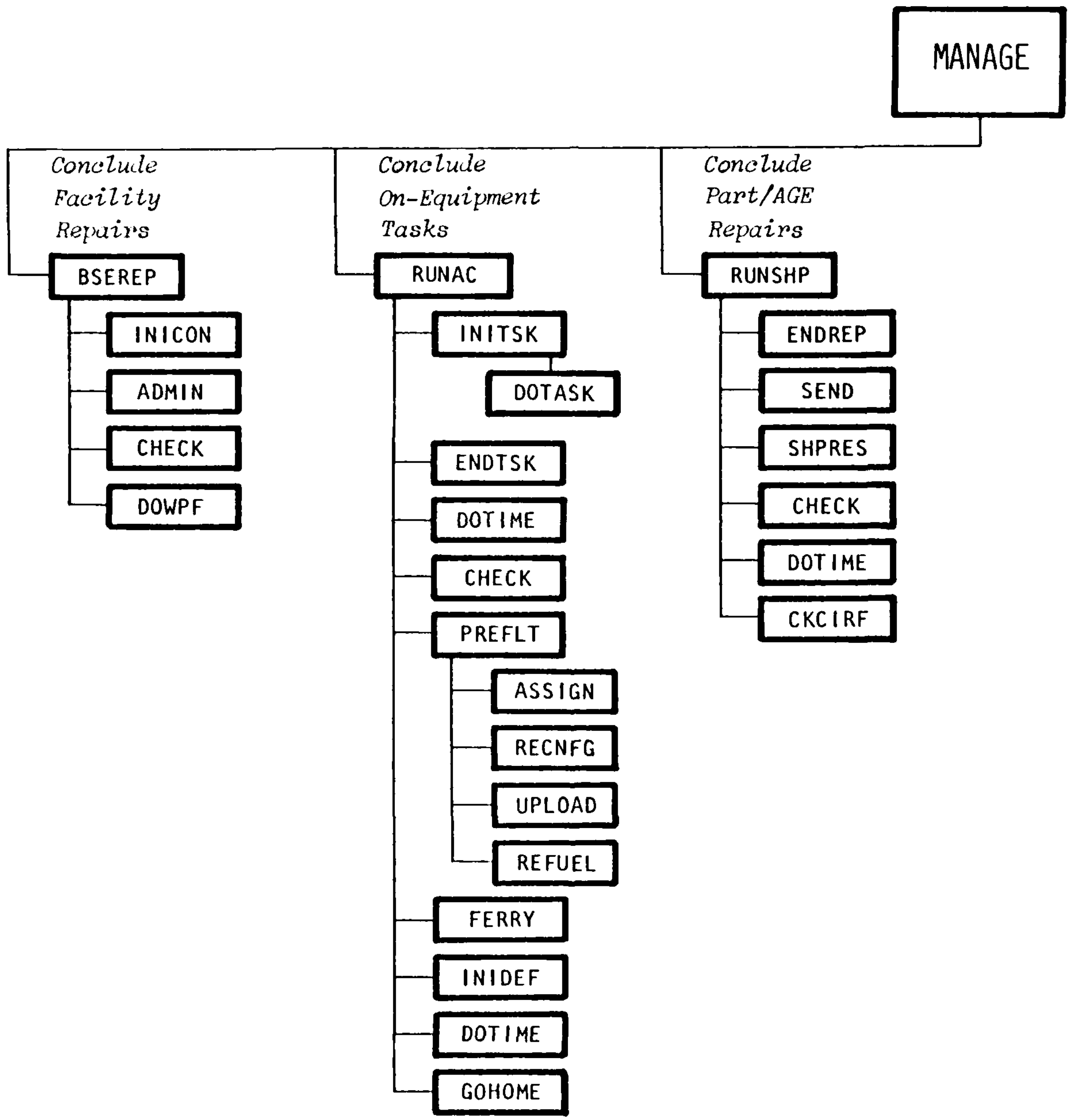


Fig. 3--Subroutines Used to Conclude Aircraft Maintenance, Parts and Facility Repairs

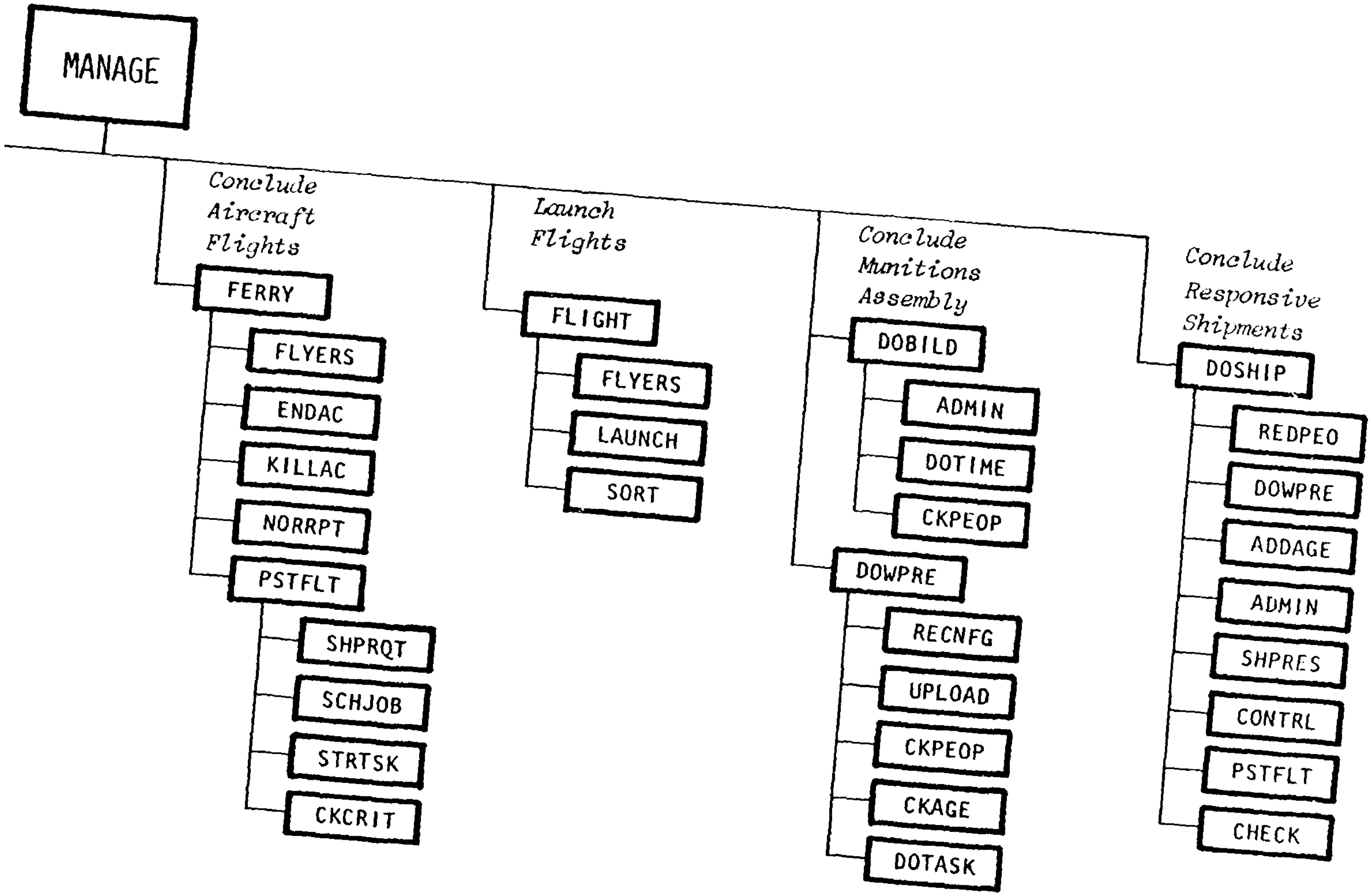


Fig. 4 -- Subroutines Used to Conclude Other Activities

when on-equipment tasks, parts and equipment repairs, munitions assembly jobs, and faulty repairs are complete. In addition, a variety of scheduled and periodic activities that are necessary during the simulation are processed by the several subordinate subroutine clusters shown in Fig. 5.

To facilitate processing and to avoid the necessity of searching extremely long time-ordered queues, the primary event structure in TSAR is divided into the eight different sets of events that have been depicted. Each of these sets is organized such that the next earliest event in each set is always known. Whenever an event is completed, the eight sets are examined in the following order for the next earliest event:

1. Civil engineering reconstruction job completion times
2. On-equipment aircraft maintenance completion times
3. Parts-repair and equipment repair completion times
4. Periodic and scheduled events
5. Aircraft delay completion times
6. Aircraft flight demands
7. Munitions assembly task completion times
8. Resource resupply arrival times

If two or more of these events occur at the same simulated time, they are processed in the order listed. The order chosen tends to limit the processing requirements.

The nature of these events varies substantially; all except the fourth and sixth sets are groupings of event completion times for

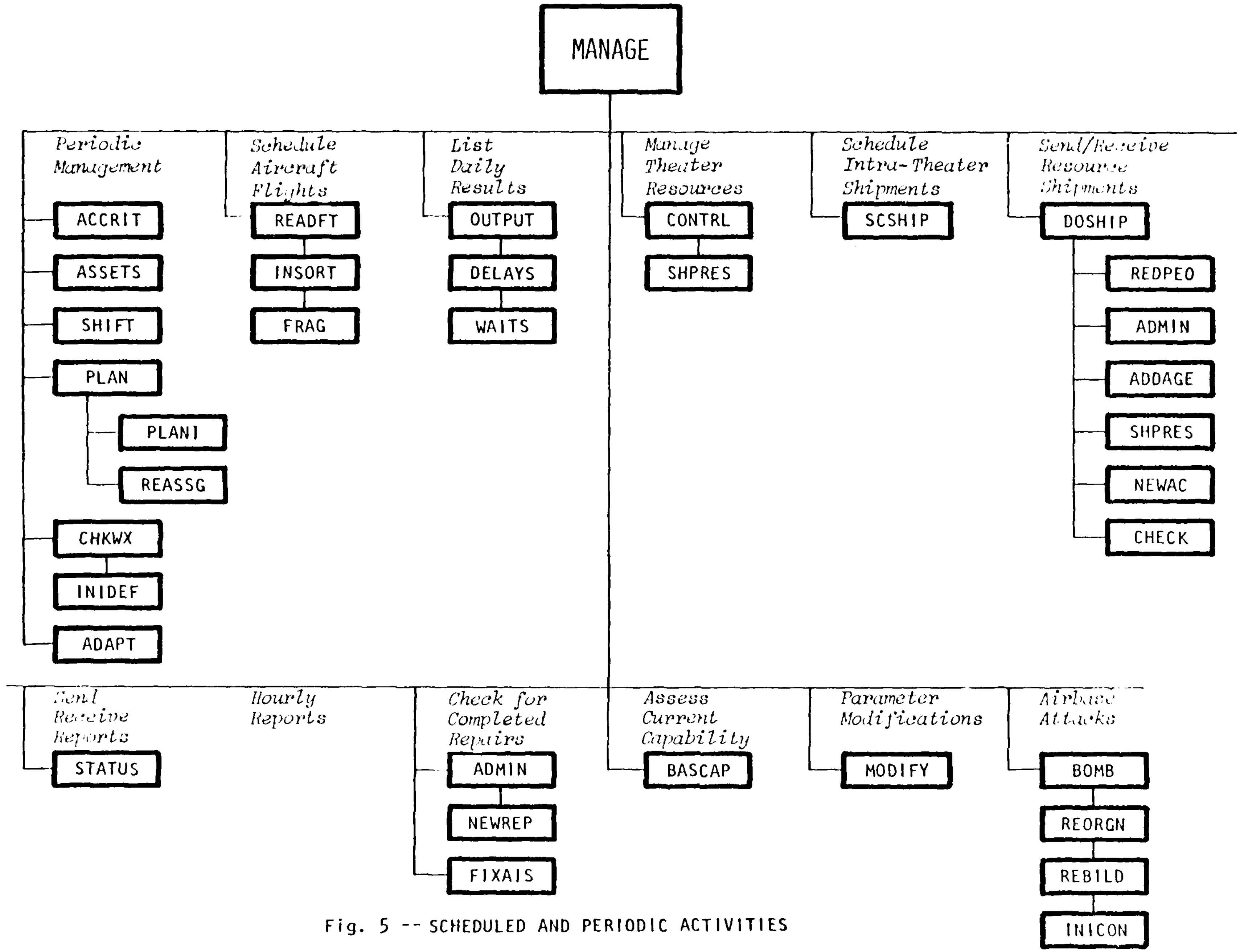


Fig. 5 -- SCHEDULED AND PERIODIC ACTIVITIES

similar types of events, while the sixth set stores the times at which groups of aircraft (flights) should be launched on various missions. The fourth set--the periodic and scheduled events--is a heterogeneous set of events and simulation housekeeping tasks that occur on a scheduled or periodic basis.

Each event set is maintained within a distinct data storage array that also stores other information that must be associated with the event. For seven of the sets, the data are organized into what has been called a "heap," which is a data structure that permits more efficient processing than a time-ordered queue when only the next earliest event must be known; the flight demand data are queued in the order in which the flights will be demanded. In one instance--the periodic and scheduled events--several of the elements in that event set are themselves the earliest elements from several subordinate "heaps" and time-ordered queues.

In many instances it is not possible to initiate events as soon as they are defined, or to pursue them without interruption, so it is necessary to store the relevant information until the resources required to pursue the tasks are available. Aircraft maintenance tasks, parts repair jobs, and equipment repairs are stored in special storage arrays if they must wait or when they are interrupted (i.e., the WAITSK and INTTSK arrays); the munitions assembly tasks are stored in the BACKLG array when resources are not available for their initiation and in the INTTSK when they must be interrupted.

The tasks that relate to each aircraft, and to each of the work centers or shops that will perform the work, are tied together with a

system of pointers (or storage location addresses). Each aircraft and each shop at each base maintains pointers to the first and the last of each of these sets of events, and the several events in the storage arrays that are associated with a particular aircraft and with a particular shop are themselves interconnected with a system of pointers. With these pointers the activities associated with any particular aircraft, or shop, that are waiting, interrupted, deferred, or in process can be readily located by examining a short trail of pointers.

The earliest times for each of the periodic and scheduled events are stored as a heap in the array PERIOD, which is maintained in subroutine MANAGE. Some of the events are periodic and some are governed by a user-supplied schedule. At this time there are 15 sets of these events:

HEAP POSITION		ACTIVITY
1	Periodic - 2 Hours	Change shifts for ground personnel Relieve aircrews Project aircraft supply and demand Reassign aircraft missions Check munitions requirements and initiate assembly Initiate deferred maintenance as Lists stocks of parts, munitions, and POL (every 6 hours)
2	Scheduled - N days	Read new flight demand data and regenerate the demand queue
3	Scheduled - N days	Regenerate flight demand data queue
4	Periodic - Daily	Print selected daily results
5	Periodic - H hours	Redistribute theater resources
6	Periodic - N days	Regenerate intra-theater shipping schedule heap
7	Scheduled (queue)	Receive inter-theater shipments
8	Scheduled (heap)	Initiate intra-theater shipments
9	Scheduled (heap)	Receive intra-theater shipments
10	Scheduled (heap)	Send and receive intra-theater resource status reports
11	Periodic - Hourly	List numbers of aircraft waiting by shop, numbers of aircraft with "holes"
12	Periodic - 2 Hours	Conclude administrative delays and process faulty parts for repair
13	Periodic - Daily	Estimate sortie generation capabilities for next 24 hours
14	Scheduled (heap)	Modify operating characteristics at a previously specified time
15	Scheduled (heap)	Airbase attacks

Whenever the processing associated with any one of these activities is completed, the next earliest activity "rises to the top of the PRAIO heap" and is considered in concert with the seven other basic sets of events.

A full description of the TSAR simulation is provided by a complete description of the steps followed for each of these several sets of events and by specification of the rules, or algorithms, that are used for the decisions regarding the initiation of follow-on actions and the disposition of the various resources that are being accounted for within the simulation. These descriptions and specifications are introduced in Sections IV through XI; Sections XII through XV provide an introductory discussion of input-output procedures and other aspects of simulation management.

In the descriptions that follow, all the features and operating modes of TSAR are treated. But the reader should be aware that TSAR can function usefully in many less complex modes, when that is appropriate. A great many of the features can be dispensed with by the simple act of not entering the pertinent data. At its least complex, TSAR would function with one aircraft, one airbase, one mission, a flight duration, a turn-around time, and a single periodic sortie demand. No resource other than the aircraft would need to be identified.

IV. UNSCHEDULED AIRCRAFT MAINTENANCE

The only constraints on the continuous recycling of aircraft in wartime are the requirements for adequate launching surfaces; the availability of aircrews, munitions, and fuel; and the necessary maintenance to permit the aircraft to fly militarily useful sorties. Of these constraints the last is clearly the most complicated since it involves complex interdependencies among a variety of resources. Without maintenance constraints, estimation of an airbase's sortie potential would be straightforward and would require little or no complex analysis. A basic reason for the level of detail in TSAR's formulation was to gain an understanding of the effect of high levels of sortie demand and battle damage on these complex processes that are needed to ready aircraft for combat and that depend on several other actions and resources.

Aircraft maintenance activities can be divided into scheduled and unscheduled tasks. The scheduled requirements include (1) periodic maintenance, performed at specified intervals of flying time, (2) certain essential ground tasks, (3) reloading basic-munitions, and (4) the preflight maintenance tasks (loading mission-dependent munitions and refueling) prior to each flight. As currently designed, TSAR does not simulate periodic maintenance, because it is assumed that such maintenance would be postponed during the critical phases of conflict. The requirements for uploading an aircraft's (non-mission-dependent) basic-munitions and mission-dependent munitions are dependent on the likelihood that the munitions were expended on the previous mission.

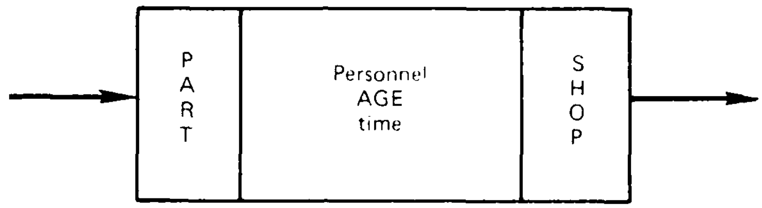
The other problems that develop and demand attention constitute unscheduled maintenance. Within TSAR, unscheduled maintenance tasks develop at random, or are generated in battle; the former are categorized as required or deferrable, on a mission-by-mission basis. Deferrable tasks may be completed after some number of sorties, before the next day's flying, or they may be deferred indefinitely if mission requirements do not require their completion. For some tasks it may be required that the aircraft be ferried to a major support base, presumably located further to the rear.

The various specialized personnel, support equipment, parts, and facilities that constitute a base's maintenance capabilities can be represented in TSAR. The personnel and equipment may support all the aircraft from a common pool, or they may be organized into sub-groups that support sub-groups (squadrons) of aircraft, and a wing-level organization that supports the several squadrons. User supplied information describes the various tasks that may be performed on an aircraft (on-equipment tasks), the personnel and equipment required to carry out the tasks and the work-center (or shop) that is normally responsible for each task. The maintenance personnel, equipment, and parts that are required for the various tasks also are assigned to a particular shop.

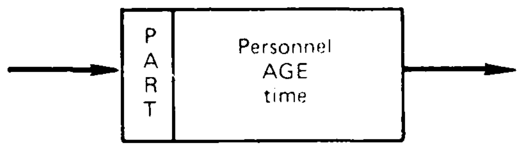
TSAR permits the user to define the requirements for each on-equipment maintenance task as either a one-step procedure, a multi-step network of sub-tasks, or a sequence of multi-step task networks. The requirements in the one-step procedure--i.e., a simple task--may include a number of each of two types of personnel, one or two pieces of support

equipment, a part, an undamaged shop, and an amount of time (specified by a mean and distribution if desired). More complex tasks that involve differing groups of personnel, equipment, and parts are represented with a task network, or sequence of networks.

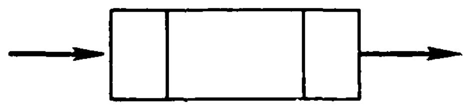
To portray these options graphically let us represent a simple task, or root segment, as:



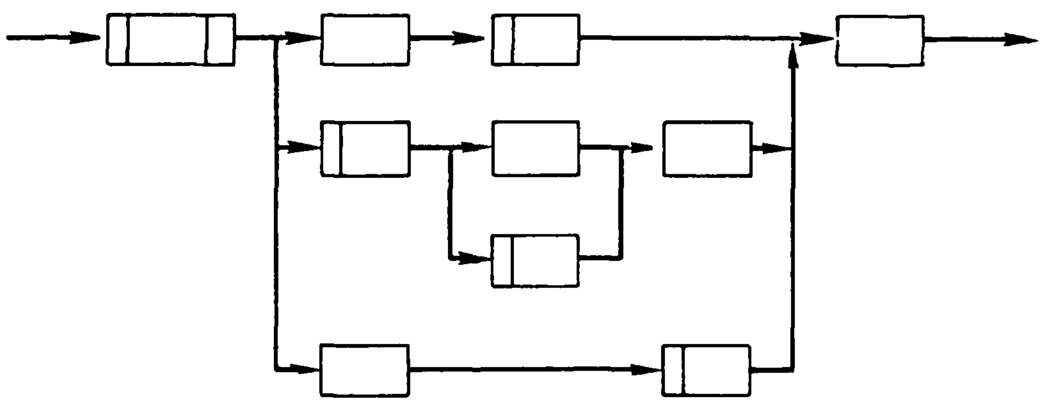
and the other segments of a task network as:



In these terms, on-equipment maintenance tasks may be represented either as a simple task:



or as a complex network of sub-tasks:

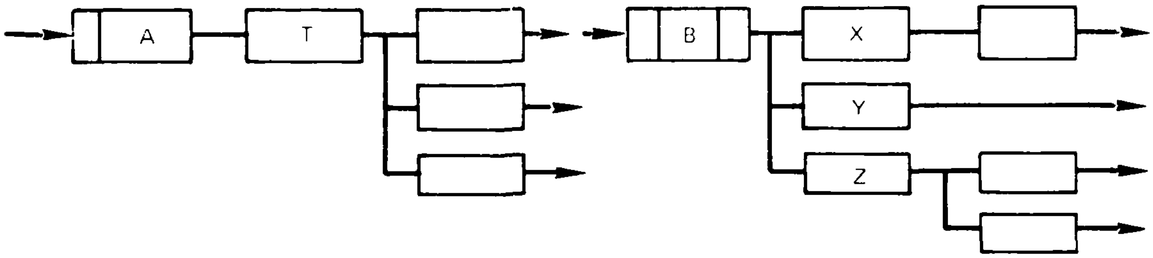


In both cases, if an intact shop facility is required to accomplish the overall task, that specification must be included with the first, or root segment. Furthermore, any particular type of part may appear in only one task segment for each type of aircraft. In this illustrative network, when the initial, or root segment, portion of the overall task has been completed, three other sub-tasks are specified for follow-on activity, followed by yet other activities. The three follow-on activities may all be required, or they may each be required on a probabilistic basis. Furthermore, some of the parallel segments may be defined as being mutually exclusive. If two or more of such parallel paths of activity must be completed before yet another follow-on activity is initiated, this can be represented by those paths rejoining before that activity. Furthermore it is permissible to represent nested sets of parallel paths that rejoin as illustrated. However, all paths that split and ultimately rejoin must all rejoin at the same place.

The segments of a task network are initiated whenever the resources for the segment are available, without reference to the availability of resources for other segments, unless the "incompatibility" conditions for the segment (see Section XIX, Volume II, Card Type #19) prohibit task initiation. Although TSAR cannot require the time-coincidence of two or more parallel segments that are performed simultaneously in real life, it can be required that all of the segments be complete before any follow-on action is begun, as was illustrated above.

The task segment that immediately follows a segment that includes a part may be made conditional on whether the part was required on that occasion; thus, in the following networks the task T and the mutually

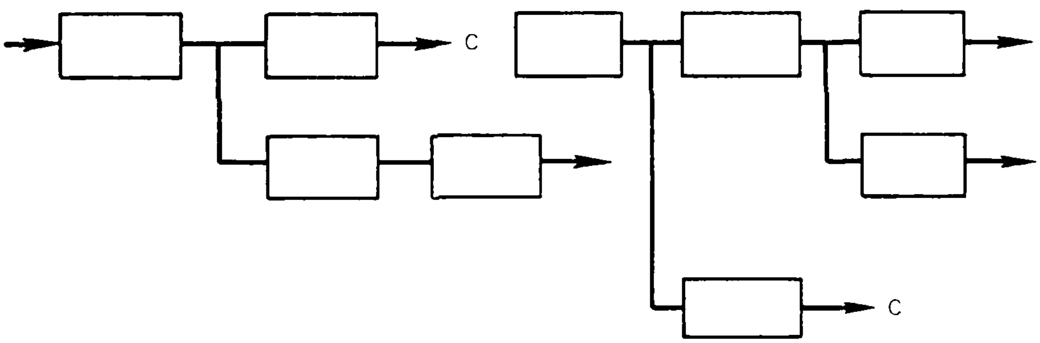
exclusive tasks X, Y, and Z may be made conditional on a part having been required in segments A and B.



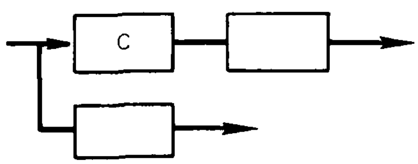
Task specification and storage may be somewhat simplified when the work procedures associated with several paths have common elements. In schematic terms the two tasks, A and B, can be defined as:

Task network A

Task Network B



where the C segment



is common to both tasks.

To be able to represent a situation that sometimes occurs in the field, any segment of a network may also specify the root segment of another network as a subsequent task; this simulates the situation

where, after work is accomplished on one job, it is discovered that the actual problem is different than initially thought. The only caution to be observed when task networks are "chained" in this manner, is that no two networks may each point to the other, either directly or through intermediate chained networks; otherwise an infinite work loop could be created.

The user may also examine the situation in which certain specialists at specified bases have received cross-training so as to be able to assist or replace another specialist on a specified sub-set of the latter's normal activities. Cross-trained personnel are assumed to perform the tasks for which they are qualified in the same time as the specialists that normally accomplish those tasks.

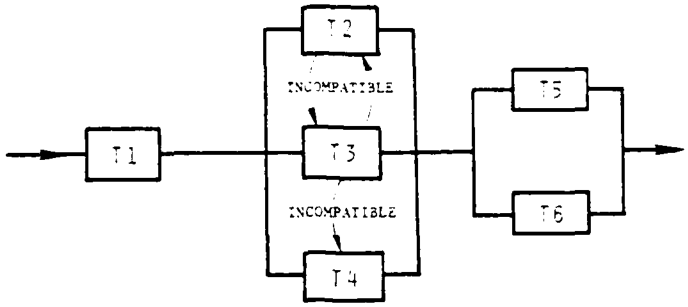
The user also may specify alternative sets of personnel and equipment for any of the segments of a task, and these alternatives will be considered whenever insufficient resources are available to accomplish the task with the normal procedures. If available, the task is accomplished with the alternate resources, without reference to the subsequent availability of the normal resources. There may be as many alternative sets of personnel, equipment, and time specified for each task segment as the user's knowledge and available data permit.

1. TASK ORGANIZATION

The organization and sequencing of the various tasks that are required on each aircraft are fully controllable[1] by the user for each

[1] Except in the special circumstance in which an aircraft must be ferried to a rear base for some portion of the required maintenance (see subsection 5, Rear Area Maintenance).

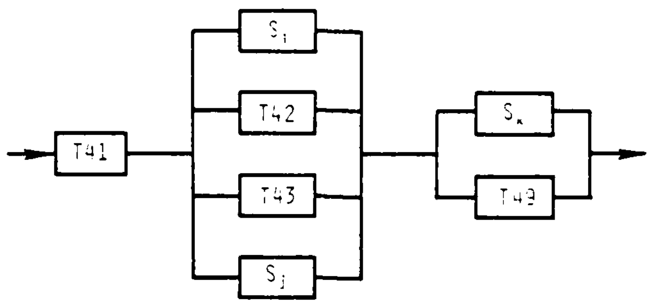
aircraft type and for each airbase. Some tasks may be pursued simultaneously, some may have to be done in a specified order, and others may occur in any order, but not at the same time. These options can be illustrated as follows:



In this instance, Task T_1 is accomplished first; Tasks T_2, T_3 and T_4 are done next, as available resources permit, except that if tasks T_2 and T_3 are both required, they may not be done simultaneously, and if tasks T_3 and T_4 are both required, T4 must be completed before T_3 may be commenced. Then, when these tasks are all completed, tasks T_5 and T_6 may be commenced; the aircraft may be launched when they are all completed. Any or all of these tasks actually may be the root segment of a task-network that must be completed before the task can be considered to be complete. Furthermore, each may occur only with a specified probability. If the aircraft had received battle damage, it can be required that this damage be repaired before task T_1 is initiated, or it may be accomplished at the same time.

The majority of the unscheduled on-equipment aircraft tasks are normally grouped together with the other tasks performed by the same work center or shop for reasons to be described shortly. Reference to

these collections of on-equipment aircraft maintenance tasks simplifies the specification of task organization as illustrated in the following sketch.



Here S_i, S_j and S_k are the collections[2] of on-equipment tasks associated with shops i, j and k. Following an aircraft sortie, each collection is checked to see whether any task associated with that shop is required. Since the majority of the unscheduled on-equipment aircraft maintenance tasks are, individually, low probability events, TSAR groups together those tasks performed by the same work center or shop and selects at most one following each flight. Processing is speeded up b this simplification (of at most one task per shop per sortie) without a serious loss in fidelity, since the joint occurrence of two or more individually low probability events would be quite unlikely.

2. TASK DESCRIPTIONS

The descriptions of on-equipment aircraft maintenance tasks fall into four categories: (1) unscheduled maintenance tasks included in a shop-task-collection; (2) "preflight" tasks; (3) battle damage repair tasks, and (4) other on-equipment tasks. With the exception of the

[2] Up to NOTASK tasks may be grouped together in each of these collections.

preflight tasks (to be discussed in Section VI), the data defining the personnel, equipment, parts, and time required for each task (and for each segment of task networks), along with the data defining the network structure and parts requirements, are stored in the TSKRQT array. If special damage repair personnel (RAM teams) are to be used for repair of battle damaged aircraft, that requirement can be imposed simply by identifying such personnel as a unique type.

Data defining the likelihood of these tasks are handled differently for each of the four categories. The likelihood that one of the tasks in a shop-task-collection is required is stored in the SHPRQT (shop requirement) array (using data input with Card Type #7). If desired, these break-rate data may be varied statistically from the input values for use in the simulation--to represent uncertain wartime break rates--or they may be varied with aircraft sortie rate for specified shops and types of aircraft (see Card Type #44).

The aircraft repair requirements imposed by battle damage are handled somewhat differently. Following each mission a random number is compared with the probability that that particular type of aircraft will be damaged on that type of mission (as specified by the user using Card Type #16). For those aircraft that are determined to be damaged, each of the battle-damage tasks specified for that aircraft type is checked; the likelihood that each task is required is specified by the task probability in the TSKRQT (task requirements) array. Aircraft repair requirements imposed by damage inflicted during airbase attacks are handled in a similar fashion, except that the tasks are added to whatever other on-equipment work is ongoing at the time of the attack.

The likelihood that the other tasks are required--i.e., those that are treated individually as tasks #41, #42, and #43 in the last sketch are specified with the other task specifications in the TSKRQT array, or, for munitions related tasks, they are controlled by the basic-munitions retention probability entered with Card Type #16. (Such tasks are associated with one of the first 25 shops but do not count toward the limit of NOTASK tasks allowed in a collection of shop tasks.)

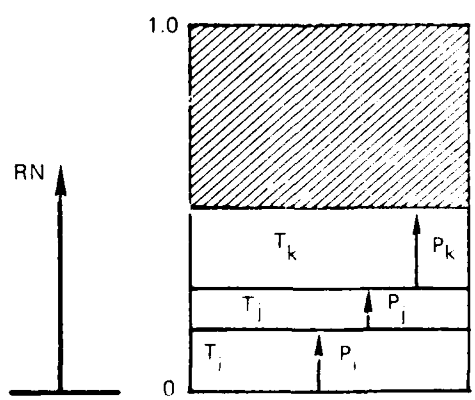
With only three exceptions, the requirements for on-equipment aircraft tasks are treated as independent activities. Two of the exceptions concern support equipment, and the other, munitions load crews. For each aircraft type, the user may specify (on Card Type #15) one or two types of support equipment for which multiple demands can be satisfied with a single item. The auxiliary power cart and the hydraulic mule are equipments that might be treated in this manner. The other exception is used to prevent a single aircraft from being assigned more than one munitions load crew; this feature is invoked when the user specifies the type and number of personnel that make up a load crew on the appropriate Card Type #15.

3. SHOPS

TSAR provides for a total of 30 shops. All aircraft maintenance personnel, equipment, and parts "belong" to one or another of these shops, and lists of the tasks and repairs that are underway, interrupted, waiting, and deferred are maintained separately for each shop. The first 24 shops are used for those collections of unscheduled maintenance tasks performed by specialists associated with each of the aircraft maintenance work centers. If desired, the personnel and equipment of each shop may be assigned to 1, 2, or 3 separate groups for supporting separate sub-sets of aircraft, and to a wing-level

organization for back-shop parts repair, as in the COMO maintenance concept. Shops 27, 28, and 29 are used for reconfiguration, munitions loading, and refueling, respectively, as outlined in Section VI. Shop 25, the "flight line" shop, is intended to be associated with those tasks other than the preflight tasks that are performed after all or most sorties and that may also involve munitions and TRAP resources. (Shop 26 is used by the program for storing references to aircraft whose mission assignment and weapons loading has been delayed, and Shop 30 is not associated with aircraft maintenance; it is used in connection with munitions assembly.)

Since, in practice, there is only a limited likelihood that the specialists from any given shop will be required for a task after any particular flight and a much smaller chance that they will be required for two or more distinct tasks, the TSAR data structure for the shop-task-collections has been designed such that at most one task from each collection will be selected after a particular sortie. With this restriction only a single random number need be drawn and compared with the cumulative sum of the probabilities of the several tasks in each collection. If the number is greater than the sum, no task is required; if it is less, the task to be accomplished is determined by the random number's position within the set of cumulative probabilities. This process may be visualized as follows:



In the situation shown, there are only three possible on-equipment tasks that the shop may be called upon to perform; T_i, T_j and T_k. The probabilities that the individual tasks are required after any given sortie are p_i, p_j and p_k. After each sortie a random number, RN, is drawn for each shop. If the value corresponds to the shaded region for a shop, no task is required; if the value is less, the task to be accomplished is the one corresponding to RN. When the user has specified that the nominal task probabilities, or break-rates, for certain shops and aircraft types should be modified in some way (as controlled by Card Type #44 data), the random number is adjusted appropriately before being compared with the shaded region.

Example

These various features for representing the organization and processing of aircraft maintenance tasks will permit the user to rapidly define and test a wide variety of different base maintenance structures. An example of an actual structure that might be defined is shown in Fig. 6.

Immediately upon landing, the user may specify a finite post-flight delay to account for taxiing, etc. This is also the point during the simulation at which TSAR determines which tasks are required, what mission the aircraft is to be prepared for, tentatively, and which required tasks may be deferred for the next mission. If the aircraft has suffered battle-damage, the repair tasks are scheduled either before any other on-equipment work or with the first set of on-equipment work depending upon the value of the control variable CONCUR. In the

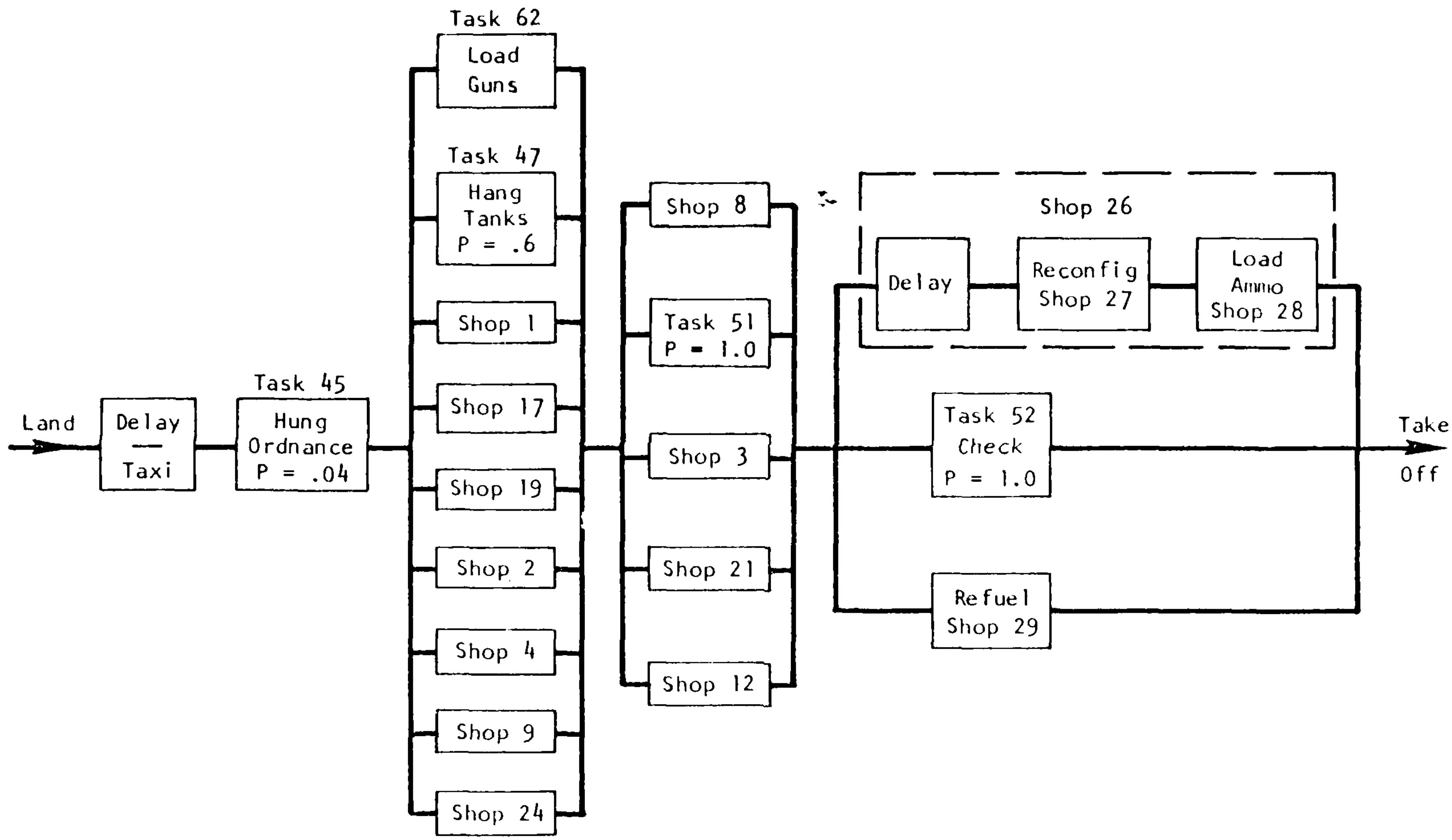


Fig. 6--Structural Representation of On-Equipment Maintenance

example, it is specified that Task #45, removing hung ordnance, occurs after 4 percent of the sorties. When that is completed, any unscheduled maintenance that is required by Shops #1, 17, 19, 2, 4, 9 and 24 may be initiated. Two scheduled tasks are also specified: the requirement to reload guns, Task #62, is not mission-dependent and is controlled by the Card Type #16 entry for the basic-munitions retention probability; the task to hang fuel tanks, Task #47, must be accomplished after 60 percent of the sorties. These tasks are different in character from most other tasks, in that some of the required resources are consumed. Tasks that may consume TRAP or munitions must be associated with the special "flight line" Shop #25 when they are not part of the mission-dependent munitions activities, or refueling activity in Shops 28 and 29.

When all of the first set of possible tasks has been completed, shop activity by Shops #8, 3, 21 and 12 may be begun, along with Task #51. And when those jobs have been completed the preflight preparations may begin. These preparations, discussed at length in Section VI, may involve a possible delay, followed by the final mission determination, aircraft reconfiguration, if required, loading of the mission-dependent munitions, and refueling. As indicated, the delay, reconfiguration, and uploading always occur in sequence and are specified by calling Shop #26. Task #52 is also indicated as being accomplished concurrently with the preflight preparations. This task as well as the other individual tasks must themselves be associated with some shop ($\leq$ #25) and use resources assigned to one or another of the shops. The munitions and TRAP tasks that must be placed in Shop #25 would use personnel and support equipment from Shops #27 and #28, while the other tasks could

call on resources normally associated with any of the first 25 shops.[3]

To specify the task sequence that is to be followed, the user enters a string of numbers using Card Types #29; a different string may be entered for each type of aircraft and for each airbase. These data are stored in the SHPORD (shop order) array. As the reader may have noticed, individual tasks must always be identified with a number larger than 30, so that they will be distinguished from a shop.

Whenever any of the required maintenance tasks is one of those that must be accomplished at a rear base, or whenever unscheduled aircraft maintenance is estimated to take longer than a user-specified length of time, the user-specified task sequence is replaced by three sequential sets of maintenance tasks. The first set, to be accomplished at the operating base, includes refueling and all tasks that would prevent the aircraft from being ferried (i.e., task criticality of 33). The second set includes refueling at the rear base, all tasks that must be accomplished at the rear base, and other of the aircraft's required and deferred tasks as are specified by the variable JOBCON (job control). The third task set, those that are to be accomplished when the aircraft returns to the operating base, includes all remaining tasks that are required.

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[3] Because of the logic used for checking on tasks that are waiting and that may need the resources that are being released from a previous task, the munitions and TRAP related jobs--those that use personnel or AGE from shops #27, #28 or #29--must be associated with shop #25.)

4. DETERMINATION OF UNSCHEDULED MAINTENANCE REQUIREMENTS

Whenever an aircraft completes a flight (and has been removed from the delay heap in the ACN array), subroutine MANAGE transfers control to entry point LAND, where checks are made to see whether the aircraft was lost on the mission or has received battle damage. If runway damage prevents aircraft recovery at the intended base, another base is selected (see Section XI.1). The flight crew is then released (see Section VIII for a discussion of that process) and, if battle damage is so severe that repair is not practical, the aircraft is written off and the various parts are salvaged to the extent specified (see Card Type #15/2). Otherwise subroutine PSTFLT (post-flight) is called. (For aircraft that have not survived or are salvaged, the existing records are eliminated with subroutine KILLAC and, if filler aircraft are available or if the user specifies replacements, another aircraft is requested using subroutine ORDER.)

The basic functions performed within subroutine PSTFLT are (1) to initiate any user-defined post-flight delay (to account for taxiing, inspection, etc.), (2) to identify what battle damage repairs are necessary, (3) to determine if any deferred tasks must be done at this time, (4) to identify newly required unscheduled maintenance requirements, (5) to determine whether any of the required maintenance must be accomplished at a rear base, and if so, to schedule aircraft refueling and transfer, and (6) to establish a tentative mission assignment for the aircraft and to categorize the newly defined tasks as essential or deferrable for that mission.

Subroutine PSTFLT establishes which of the individual tasks and which of the collections of unscheduled tasks are required and what the expected time is for carrying out the essential maintenance. When an aircraft has received battle damage, the required repairs are determined, and then the individual tasks and the shop task collections are checked in the specified order as illustrated in the preceding subsection; for each of the tasks and shops a random number is drawn to determine which if any of the tasks require attention. As the various tasks and shops are checked, the expected time to complete each task that is identified is estimated as the mean time specified for that task, plus approximate time allowances for (1) aircraft that are already waiting at that shop, (2) parts repair, when parts are known to be required and none are available, and (3) repair of the maintenance facility itself, when the task specifications prescribe that the facility is necessary to accomplish the task and it is damaged.

When the times for the required tasks and for preflight have been determined, the time at which the aircraft could be ready to fly is established for each possible mission type. If any of the previously deferred tasks are now required or are now essential for any of the missions, the time to accomplish them is included on the assumption that they would be processed simultaneously, before doing the other tasks. These ready-to-fly estimates take into account the user's specifications as to which shops may perform on-equipment tasks simultaneously and which groups of shops must follow other groups. They also take into account only those tasks that may not be deferred for each particular mission. By making the estimates in this manner, the nominal times at

which the aircraft could be readied for the various missions will typically differ for the different missions, and these times will also include at least a rough accounting of the queues, parts shortages, or facility damage that might interfere with the preparations for one mission, but not another.

Unless the aircraft is scheduled to be ferried to the rear for maintenance, as discussed below, the next step is to determine the highest priority mission that has insufficient aircraft to meet the known demand, between the times that the aircraft could be ready for variance missions and the time horizon for planning. If the deficient priority is no higher than that for the aircraft's previous mission and occurs no earlier, the aircraft is committed to the same type of mission that it just completed. Otherwise, the aircraft is tentatively committed to that mission with the earliest, highest deficient priority.

The unscheduled maintenance tasks that are essential for the designated mission are stored in the RQDTSK (required task) array and the others are placed in the DEFTSK (deferred task) array. Final bookkeeping in the PSTFLT subroutine includes updating the aircraft's criticality index (i.e., ACN(-,17)), which maintains a record of which missions may be flown despite the maintenance that has been deferred.

5. REAR AREA MAINTENANCE

Aircraft may be sent to a rear-area maintenance base either when specially designated tasks must be accomplished, or when the estimated completion time for the required maintenance exceeds a user specified time (MNTLMT). Both regular unscheduled maintenance tasks and battle-

damage tasks may be specially designated as requiring action at a rear maintenance base; these task designations may apply to all aircraft, or only to aircraft at a COB. Naturally, the criticality of any such task must be such that the aircraft may be ferried. If the user has specified a time limit for maintenance at forward operating bases (MNTLMT), and the estimated maintenance time exceeds that value, a check is first made that there is at least as much time for the maintenance in the rear as what must be done at the operating base. If so, and if the time required for the maintenance that must be done at the operating base is as great as MNTF percent of MNTLMT, another check is made to see that the time for the maintenance that may be done in the rear is at least equal to MNTR percent of MNTLMT. When this final check is exercised, it provides the user with a somewhat more realistic control over which aircraft are sent to the rear and which are not.

After an aircraft has landed and its ready-to-fly time has been estimated in subroutine PSTFLT, as discussed above, a check is made to see if aircraft maintenance is to be done in the rear. If (1) tasks that must be done in the rear are outstanding, or (2) the ready-to-fly time exceeds MNTLMT, etc., the required tasks are regrouped into three sets. The first includes a refueling and all tasks that prohibit the aircraft from being ferried. The second set includes a refueling and all tasks that must be done in the rear, as well as whatever other tasks are to be accomplished, as defined by the value of the control variable JOBCON (see Section XIX); these tasks are scheduled for the rear base. The third set of tasks includes a refueling and all other tasks that are outstanding and the necessary munitions loading tasks; these are

scheduled for accomplishment on return to the operating base. No additional maintenance requirements are assumed to be generated on the return flight to the operating base. To the extent practical, the ordered structure for maintenance tasks that is prescribed with the Type #29 Cards is maintained within each of the three task sets.

Aircraft spare parts for rear area maintenance bases are either individually stocked or, when the automatic parts generation feature is being used, they are acquired by redistributing the spares that are calculated for the operating bases. For tasks that must be done in the rear, all parts are placed in the rear. An estimate is also made of the fraction of the other tasks that will be accomplished at the rear base at the same time that the mandatory work is underway, and a like fraction of all parts is placed in the rear. If aircraft are also sent to the rear whenever the ready-to-fly time exceeds MNTLMT, etc., the fraction of the parts placed in the rear can be increased by the user's specification of RPARTS.

6. AIRCRAFT MAINTENANCE MANAGEMENT

After an aircraft's next mission has been tentatively selected and the various scheduled and unscheduled tasks have been defined in subroutine PSTFLT, subroutine MANAGE transfers control to subroutine RUNAC, which manages the initiation and termination of on-equipment maintenance tasks until the aircraft has been prepared for flight.

When first called, following the optional postflight delay, subroutine RUNAC is entered at entry point STARTM (start maintenance). TSAR immediately attempts to initiate the required work on each of the

first set of required tasks stored in the RQITSK array by calling subroutine INITSK (initiate task) through entry point NEWTSK. When an aircraft has sustained damage in battle those tasks are scheduled first, unless CONCUR is unity. If the required resources are available to initiate a task, they are withdrawn from stock, the task completion time is determined (using TTIME), and the activity is placed in the TASKQ heap; if resources are not available the task is placed in the WAITSK (waiting task) queue of the appropriate shop. (The operation of subroutine INITSK will be discussed more fully in the next subsection). When all of the tasks that may be performed simultaneously have been processed, control is returned[4] to MANAGE for other operations.

Subroutine RUNAC is also called whenever an on-equipment task has been completed. The first step is to call subroutine ENDTSK to release the resources[5] and to assign them to tasks that may have been interrupted or are waiting (by using subroutines CHECK and DOWPRE for unscheduled and preflight tasks, respectively). When ENDTSK returns control to RUNAC the next step depends upon the nature of the task. For unscheduled maintenance tasks a check is made to see if the task is an element in a task network, and if it is, resources are checked to start any subsequent task or set of parallel tasks. A check is next made for

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[4] When late takeoffs are permitted, each aircraft is also checked to see whether its estimated ready-to-fly time is sufficiently close for it to be considered. If other tasks remain to be checked, but the estimated time is within two hours, the flag--ACN(-,21)--is set so that the aircraft could be considered for a possible late takeoff. The flag is also set if all tasks have been started and the completion time is within three hours, or when only one task remains, has been initiated, and is expected to be completed within four hours.

[5] Except for specific types of equipment that may need to be retained for use on other ongoing tasks.

any tasks that may have been forced to await the completion of the just concluded task, because of an incompatibility (as defined with Card Types #19), and any such tasks are initiated, if resources permit.

If at this point on-equipment tasks are in process, control is returned to MANAGE; if no tasks are in process but tasks are still waiting for the appropriate resources, a new estimate is made of the ready-to-fly time before returning control to MANAGE. If there are no tasks in process or waiting, but tasks remain in the RQDTSK array, a new estimate of the ready-to-fly time is computed, and the next set of required tasks are checked and initiated as resources permit. If no tasks are in process or are waiting, and there are no further tasks required, a check is made to see if conditions permit deferred maintenance to be accomplished at this time; operations in this circumstance are discussed in a subsequent subsection.

When subroutine RUNAC is called at the completion of a preflight task, operation is somewhat different than with unscheduled maintenance tasks. After the resources that have been in use are released (and an attempt to reuse them made with subroutine DOWPRE), subroutine RUNAC calls subroutine PREFLT (preflight) that manages the unique task structure used with preflight tasks; these operations are described in Section X. When control is subsequently returned to subroutine RUNAC, processing continues in much the same manner as for unscheduled maintenance tasks, except for the task network tests.

One other key feature of the management operation performed in subroutine RUNAC permits the preflight tasks to be deferred in certain circumstances, so that the final decisions regarding mission assignment

and munitions may be delayed until further information has been received regarding sortie demand. When these conditions (as discussed in Section X) have been met and the preflight delay flag DELYPF has been set to unity, the mission assignment and weapons loading tasks (i.e., Shops #26, 27 and 28) are allowed to wait while the other tasks are processed in accord with the specified shop-task structure (i.e., the shop sequence data from Card Type #29). When all required tasks are complete, deferred tasks will be initiated if it is estimated that they can be completed before the user-specified last allowable hour for commencing the weapons loading procedures (i.e., LSTTOD). If none can be started, or if all deferred tasks are completed before LOADTM (the earliest hour for commencing to upload munitions), a preflight delay is computed such that it will just be completed at LOADTM, and the aircraft is placed in the delay heap in the ACN array.

7. ON-EQUIPMENT TASK INITIATION

On-equipment maintenance tasks, except for the preflight tasks, are initiated with a call to subroutine INITSK (initiate task). This subroutine is initially called from RUNAC; if tasks must wait or are interrupted after they are initiated, subroutine CHECK subsequently calls to recheck the availability of the required resources.

When subroutine INITSK is entered to check for tasks that have been waiting or interrupted, a rough check is made of the existing ready-to-fly time estimate for the aircraft; if it is outdated a crude update is calculated. When a part will be required, base stocks are checked to see if one is available. The task is then checked to see if it must be

delayed because other work in process is incompatible. If there is no problem, the program next checks for the availability of any facility that may be required and for the personnel and equipment specified for the task. If it has been specified that only one item of the required type of support equipment is needed for several tasks, and one is already assigned to the aircraft, the additional requirement is ignored; similarly, if an aircraft is not to be assigned two or more munitions load crews, and one is already at work, the task is delayed. If the aircraft is assigned to its own squadron with its own personnel and equipment, the required resources are drawn from the appropriate group. If a facility is needed and it is unavailable, or if insufficient equipment is available, the shortage is noted and the program transfers to check any alternative procedures that the user may have stipulated for this task.

Subroutine GETPEO is called to check on the availability of the required personnel, and subroutine CKAGE establishes the availability of any equipment that is required. If insufficient personnel are available, but on-base personnel have received cross-training, checks are made to see whether such personnel can be used on this task, and, if so, subroutine CKPEOP is called to see if sufficient cross-trained or task-assist-qualified personnel are available. If there are not, but the required number of specified personnel are involved in parts repair activities, those repairs are interrupted to acquire the personnel needed for the on-equipment task,[6] when the needed part is in stock.

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[6] This could occur in a 66-1 type organization but not in a COMO (66-5) organization, since the parts repair personnel at wing level in COMO are differentiated within TSAR by means of a different identity.

The time remaining to complete the interrupted repair is stored with the other repair data in the INTTSK (interrupted task) array. If the required maintenance specialists cannot be obtained by these procedures, the last option is to stop an ongoing maintenance task on another aircraft. This will be done only if the ongoing task has at least two hours remaining until completion and if the aircraft has a projected ready-to-fly time at least four hours later than the aircraft for which the personnel are sought.

If sufficient personnel are available, but a needed part is not, a check is made to see if it may be obtained from another aircraft by cannibalization: the various options that exist for cannibalization will be discussed in a later subsection. If a part is not located, the fact that the aircraft has a "hole" is filed by calling subroutine RPTNOR (report not operationally ready); if the rules prescribed by the user permit (see Section XI), an attempt is made to locate the needed part at another location in the theater and to have it shipped.

If all resources are available the task is initiated with a call to subroutine DOTASK that places the task in the TASKQ heap and also places pointers defining its location in the in-process queues associated with the aircraft and with the shop that is doing the work. The duration of the job is determined on the basis of the mean task time and the distribution specified by the user. The user may also represent various actions to speed up and expedite the various maintenance activities by adjusting the appropriate control variables. (See the discussion of subroutine TTIME in Section XIV.)

The DOTASK subroutine is also used when it is necessary to stop an on-equipment task. Since on-equipment tasks receive priority over parts repair tasks, the only times that on-equipment tasks are interrupted is (1) when a task is stopped for a higher priority on-equipment task, (2) when the number of personnel at a shop is reduced because of a shift change, or (3) when the airbase is attacked and shop personnel are lost. At those times the subroutine is entered at the entry point STPTSK (stop task), and the needed bookkeeping is done on the pointer systems used with the aircraft, the shops, and the INTTSK and TASKQ arrays. When personnel are reduced because of a shift change, the last task that was initiated is the first to be interrupted.

If a part is available, but some other resource prevents the task from being initiated, any alternative procedure (set of resources) for accomplishing the task that has been supplied by the user is checked to see if those resources are available. If they are, the task is initiated using the alternative procedure; if they are not, the task must wait in the appropriate shop's wait queue. If the task had already been waiting, processing is complete. If it is being checked for the first time, subroutine ACWAIT is called to store the relevant data in the WAITSK array; the resource for which a shortage prevented the primary procedure from being initiated, is taken to be the reason for the delay. When the task is placed in the shop's wait queue it is placed last in line if ORDWT=0; if ORDWT=1, subroutine INWAIT is called and the task is placed in the shop's wait queue such that the aircraft with the least time remaining before it had been estimated to be ready to fly is placed first.

The last step for a task that is being checked for the first time is to dispose of any part that must be removed from the aircraft. If the part is not reparable in the theater, it is eliminated and another may be requisitioned from CONUS. If it is not reparable at the base where it was removed, it is shipped to whatever location has been specified for its repair (using the SHIPTO array data input from Card Type #34). It may be shipped directly after removal from the aircraft, or it may first have to be checked on base.[7] If the part can be repaired on base it is sent to the appropriate repair facility.

The part is removed from the aircraft when the task is first checked, even though the resources were not available to start the on-equipment task at that time; it is assumed that the overall resource demands for the task are adequately approximated by the task's resource requirements whether they are used then or later. The repair of the part is delayed by a time equal to the sum of the nomimal task time and the backshop administrative delay time (see Section VII).

If the task started in INITSK is a task that had already been started but had been interrupted, or is a task that had already been checked but had had to wait, the necessary bookkeeping for the pointers is accomplished before control is returned to MANAGE.

Of the many data maintained for each aircraft, two are flags used to rapidly identify each aircraft's current status; the first flag (stored in the 12th position of the aircraft array--i.e., ACN(-,12)--

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[7] Any part, LRU, or SRU with a NRTS rate of 101 is shipped directly after removal from an aircraft (or from an LRU); if the NRTS rate is from 1 to 100, the part must undergo the administration delay before being checked for NRTS action.

defines the aircraft's location within the overall sortie cycle, while the second flag (ACN(-,16)) defines the degree to which the aircraft has progressed through the several steps in the preflight process. The states corresponding to various values of the first flag are:

ACN(-,12)	Aircraft Status
1	In flight
2	Inactive for the postflight delay
3	Undergoing unscheduled maintenance
4	Inactive for the preflight delay
5	Undergoing maintenance following the preflight delay
6	Ready for flight
7	Undergoing deferred maintenance tasks

The several preflight states defined by the second flag are outlined in Section VI.

8. CANNIBALIZATION

When a part must be replaced on an aircraft and a replacement is not immediately available, TSAR may be directed to cannibalize the needed part from another aircraft in certain circumstances.[8] The rules governing cannibalization are managed by the user with his setting of the control variables CANMOD (cannibalization mode), MXHOLE, DOCANN, DOWNTM, and CDELAY. The basic user choices are (1) whether a part may be cannibalized when there are reparables on base, and if so (2) which of the aircraft may be considered. The aircraft that may be considered

[8] Parts cannibalization may be selectively prohibited by entering '-1' for a specific part type in the CANNTM array using Card Type #35. If the value is less than -1, the part may only be cannibalized when at least DOCANN aircraft already need that type of part.

must be of the same type and must also be undergoing unscheduled maintenance. Four possible categories are defined: aircraft with parts missing, whose criticality for the designated mission would not be affected; all aircraft that have parts missing; aircraft without holes, if the criticality would not affect the designated mission; and all other aircraft. If cannibalization is selectively restricted to aircraft in either of the first two categories, the donor aircraft must have at least as many missing parts (i.e., "holes") as the recipient aircraft. No matter which category is chosen, aircraft that already have a part missing are checked before the others are checked. Parts not normally cannibalized can sometimes be cannibalized if sufficient aircraft already need the same part.[8] The user may also prohibit cannibalization of the part from any aircraft that already has had MXHOLE parts removed, or whose estimated ready-to-fly time is within DOWNTM hours; for aircraft without "holes" TSAR has a built-in minimum constraint of 90 minutes for this time.

These optional constraints are defined for various values of the control variable CANMOD as follows:

Cannibalization Constraints*

CANMOD	Cannibalization Permitted with On-base Reparables	Eligible Aircraft (None with ready-to-fly time less than DOWNTM hours-- $\geq$ 90 minutes)
0		None
1	No	Aircraft with parts missing whose criticality for the designated mission would not be affected
2	Yes	Ditto
3	No	Aircraft with other missing parts
4	Yes	ditto
5	No	Aircraft whose designated mission is not affected by part
6	Yes	ditto
7	No	*Any aircraft*
8	Yes	ditto

*Parts that may be cannibalized only when the DOCANN constraint is satisfied are distinguished by an entry in the CANNTM array that is less than -1.

Cannibalization is accomplished in subroutine CANNIB. When an aircraft is checked for the needed part, the waiting tasks, required tasks, and deferred tasks, are checked first in that order. If the same task is found to be required on the aircraft but the part is not required (i.e., is not broken), it is assumed that the part can be removed; if the part may be required in a subsequent segment of the task network, it is assumed that the part is not available. If the task is not found in any of those categories, the in-process tasks are checked; if the same task is not being processed, the aircraft is considered suitable for cannibalization.

When a part is removed from an aircraft, data regarding the new "hole" is stored in the NORQ array using the NORRPT subroutine (see Section XIV) and is recorded with the related task data by modifying the number of the task (see below). And when the part is removed from an aircraft for which the related task was not already outstanding, a notice to replace the part must be added to that aircraft's list of required tasks or deferred tasks.

To be able to keep track of the state of an aircraft's tasks and related parts a special scheme was created for numbering tasks. If the basic task number is TASK the value stored for the task depends upon the task's status as follows:

Value Stored	Status
TASK	No part required
TASK + 5000	Part required, not yet recorded in NORQ array
TASK + 10000	Part required, recorded in NORQ array
TASK + 15000	Part required, part removed, not yet recorded
TASK + 20000	Part required, part removed and recorded
TASK + 25000	Replace part only, ignore network, part removed, recorded
TASK > 30000	Preflight task

When a part is cannibalized from one aircraft to permit work to be carried out on another aircraft, the time required to get the part and to complete the basic task on the receiving aircraft is the sum of the time normally required for that task, plus either the time for cannibalizing a part of that specific kind (from the CANNTM array), or the default cannibalization time; the latter is equal to one-half the true time selected for the task plus CDELAY minutes, as defined by the user with the control variable CDELAY.

9. ACCOMPLISHING DEFERRED MAINTENANCE

On-equipment aircraft maintenance that has been deferred as nonessential for an aircraft's designated mission may be taken care of in four different ways. The first possibility (mentioned in the first subsection) is that a different mission will be chosen for the aircraft for a subsequent flight and the deferred task will become mission essential and be transferred from the DEFTSK array to the required tasks in the RQDTSK array.

The second possibility is that a deferred task may be deferrable only for some number of sorties (LTHDEF sorties) or until the end of the nominal flying day. In the first instance the task will be redefined as a required task after the LTHDEF sortie, and in the other it will be redefined when subroutine INIDEF is called after the end of the flying day, as discussed next.

All deferred tasks are reviewed each evening after the end of what the user has designated as the "flying day"; i.e., after ENDAY. At those times subroutine RUNAC calls subroutine INIDEF (initiate deferred maintenance) when all other tasks outstanding for the aircraft have been completed, except, perhaps, for the preflight task set that may have been delayed until the early morning hours. Subroutine INIDEF is also called at 2000, 2200 and 2400 during the night by subroutine PLAN to check for needed resources that may have been released by other tasks.

At these times, subroutine INIDEF redefines as required the deferred tasks that must be accomplished at night, and also attempts to initiate each of the aircraft's deferred tasks, if the nominal time for the task will permit it to be completed no later than the hour specified by the user as the last time at which the rearming process must commence (i.e., LSTTOD--last time of day). After checking that tasks aren't already waiting at the task's designated shop, the INITSK subroutine is called to check on the availability of necessary resources. If available, the task is begun; if not, it is left as a deferred task rather than being redefined as a waiting task, since that status would prevent further actions with that aircraft. When the task data have been filed in the TASKQ array the mission-capable status of the aircraft is updated.

The fourth possibility for working-off deferred maintenance tasks occurs on those days for which the user has specified that the weather will not permit operations at a particular base for specified aircraft types. Subroutine MANAGE calls subroutine DODEF (do deferred tasks) periodically and the weather status is checked for each base and each aircraft type at four hour intervals starting at 0400, when it is presumed that the day's weather conditions will be known. For all aircraft that are otherwise ready to fly, subroutine INIDEF is called and that subroutine checks whether available resources will permit that aircraft's deferred tasks to be started and completed by the LSTTOD on the following day. This processing follows the same rules as were described in the preceding paragraph.

V. AIRCRAFT STATUS PROJECTION

It is important that a simulation of airbase operations emulate at least in a limited way the scheduling and control activities that are carried out by the job-control shop at each airbase in order to utilize the available resources efficiently. Choices must be made as to the tasks to be performed, repairs to be done, munitions to be assembled and aircraft assignments. In the real world these choices are made in the context of a much richer body of knowledge regarding assets, capabilities and requirements than is possible (or at least practical) in a simulation. Furthermore, the procedures used and results obtained in the real situation are, at least in part, dependent upon the skill, knowledge, and experience of the particular job control managers available, and vary therefore from one circumstance to another. All that reasonably can be expected of a simulation are mechanisms to allow the user to define broadly differing policies for managing aircraft maintenance and repair jobs and to achieve a degree of efficiency in the utilization of the available resources.

TSAR incorporates a variety of features for these reasons, a key one of which is the periodic development of what might best be called the projection of aircraft supply and demand. These projections provide the data base, or context, within which decisions are made regarding aircraft assignments, unscheduled maintenance, and munitions buildup for the subsequent two-hour period.

As is outlined at greater length in Sections VIII and XIX, the sortie demand data specifies the airbase, the aircraft type, the

mission, the number of aircraft, the mission priority, the receipt time of the demand, and the desired launch time. Provisions are included that also permit the user to stipulate that a number of aircraft of a particular type be maintained in an alert (cocked) status, so that they may be launched whenever they are needed for a specific mission. These data provide the information with which the pattern of sortie demands is projected.

Since the current status of each aircraft assigned to a base is known at any particular time, one may also make a projection of when sorties of various types might be launched. These projections are also made every two hours for each base, each aircraft type, and each mission for each of the several priority levels. By comparison of these two projections, aircraft assignments are made so as to give priority to the more urgent, higher priority demands.

These projections are accomplished in subroutines PLAN and PLAN1 and the essence of the supply and demand comparison is stored in the SORDEF (sortie deficiency) array for use as decisions are required. The time horizon for these projections is controlled internally and may be made a function of the time of day: the time to the time horizon is divided into 16 time blocks.[1] The sortie demand times and estimated aircraft ready times are placed into that time block into which they fall.

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[1] The time horizon is controlled either by the user or by the default conditions; as currently written, the default conditions are: a planning horizon of 12 hours from midnight to 0400, 8 hours from 0401 till 1600, 20 hours from 1601 till 2000, and 16 hours from 2001 till 2359.

1. PREPARING THE PROJECTIONS OF SUPPLY AND DEMAND

Subroutine PLAN is called by MANAGE on even-numbered hours, and the first step is to estimate aircraft supply. Each base and each aircraft is checked and the estimated ready-to-fly time determines which time block is credited with an available aircraft. The ready-to-fly time is determined either by the value that was estimated when the maintenance requirements are determined in subroutine PSTFLT (and occasionally updated) or, for those aircraft that are currently in flight, the ready-to-fly time is projected on the assumption that the aircraft will be reassigned to the same mission and will spend a nominal amount of time in unscheduled maintenance (as specified by the user with Card Type #15). These data are collected for each mission and for each aircraft type and stored temporarily in the SUPPLY array; they are then converted to cumulative distributions over time, and subroutine PLAN1 is called to project the demand and derive the needed comparisons. The ACA (aircraft assignment) array is updated at the same time for the aircraft that are currently on base and have already been assigned to specific flights.

Subroutine PLAN1 is called separately for each type of mission, each type of aircraft, and each base. The demands for each such subset are first collected for the highest priority demands--Priority #1--in array DEMAND and converted to a cumulative record in array SUM. The aircraft supply for that mission and aircraft type (that was stored in the SUPPLY array) is then projected ahead on the assumption that available aircraft will be launched when required for the first priority flights and will return, and be turned around in the nominal sortie cycle time specified by the user with Card Type #15. The projected

surplus or deficiency during each time interval for first priority flights is then stored temporarily in a local array. This entire procedure is then repeated for each of the lower priorities, with the continuing assumption that all higher priority flights are also flown and subsequently turned around, when sufficient aircraft are available.

Three data are then stored in the SORDEF (sortie deficiency) array for each of the 16 time blocks. The total demand at all priority levels during and subsequent to each time interval is stored in the first position; the highest priority level at which a deficiency is projected to exist is stored in the second position; and the number of sorties expected to be available at the highest deficient priority level is stored in the third position. These data are used in assigning aircraft during the subsequent two hour period.

When these data have been prepared for all bases, aircraft types, and missions, four final actions are carried out in PLAN. The first is to check whether the flag that will delay the preflight procedure should be set. If the nominal flying day is complete--i.e., it is ENDAY or later--the DELYPF flag is set to permit the preflight process to be delayed and deferred maintenance to be initiated.

The next action in PLAN is to collect the total number of known sortie demands for each type of aircraft and mission at all bases and to store that information (in ACMDTA(12,-,-)) for use in the CIRF repair algorithms. Then, subroutine REASSG (reassign) is called to check

whether more aircraft have been readied for a mission than are needed; if so, they are reassigned to a mission that is deficient. The last activity, conducted at 2000, 2200 and at midnight, is to check that all maintenance that had been deferred until night will receive attention.

VI. PREFLIGHT TASKS AND MUNITIONS BUILDUP

The preflight events dealt with by TSAR include a preflight delay, final mission assignment, aircraft reconfiguration, loading of mission-dependent munitions, and refueling. Additional munitions--i.e., the basic munitions that are always to be carried--will normally be entered separately as individual tasks, as explained in Section IV. The other tasks to be discussed in this section in connection with the preflight tasks are the munitions buildup tasks. The procedures and resources associated with these events are sufficiently different in detail that nine special subroutines were developed. When the basic control for aircraft maintenance is passed to subroutine RUNAC by subroutine MANAGE, the management of the preflight events is further delegated to subroutine PSTFLT, as was mentioned in Section V; for the munitions buildup tasks, MANAGE transfers control directly to MUNEED or DOBILD.

Before discussing the various rules that govern these events in TSAR, some definitions and conventions should be outlined. The preflight delay was envisioned as a period of dead-time that the user might wish to specify before the munitions related events and (typically) subsequent to the completion of the unscheduled maintenance tasks. When it is necessary to delay the preflight events until after the expected receipt of sortie demand information (as discussed in Section V), the length of this delay is modified endogenously. Immediately following this delay a final determination is made as to the next mission that the aircraft will fly and a tentative assignment is made to a specific flight, alert force, or set of spare aircraft. These

selections are based on the most recent projections of aircraft supply and sortie demand (Section V) and may involve a change of mission from that designated tentatively at the time of postflight "inspection." After TSAR determines the appropriate aircraft configuration required for the most effective munitions that are available for the next mission, the aircraft is reconfigured, as necessary, and the weapons are loaded if they were not retained from the prior sortie.

The periodic projections of aircraft supply and sortie demand are also used to generate the demands for munitions buildup. The munitions demands imposed by the sorties that are expected to be flown are compared with the available and in-process munitions, and work is initiated to offset any apparent shortfall. The prescribed procedures give priority to the earliest high-priority sorties that have been demanded.

Several TSAR work centers, or shops, are set aside exclusively for use with the preflight events. Shop #26 is associated with the preflight delay and assignment, Shop #27 with reconfiguration, Shop #28 with mission-dependent munitions loading and Shop #29 with refueling. Shop #30 is responsible for all munitions buildup tasks. As discussed in Section V, the "flight-line" shop, Shop #25, also can be used in connection with the basic munitions and certain TRAP.

When the preflight events, or tasks, are listed in the user-supplied shop sequence data, as described in Section V, Shop #26 and Shop #29 may be listed in any sequence with the individual tasks and other shop numbers. However, the most logical arrangement would be to list Shop #26 (which implies mission assignment, reconfiguration, and

mission-dependent munitions uploading) as, or with, the last group of shops. Thus, if one had designated only four maintenance shops, and listed the shop sequence as 1, 2, 3, 4, 29, 0, 26, 0, 0, all tasks would be processed as quickly as resources and task incompatibilities permitted, except for the mission-dependent munitions tasks that would be accomplished last. If, however, the sequence were listed as 1, 2, 0, 26, 0, 29, 3, 4, 0, 0, the work required by Shops 1 and 2 would be completed first, the final mission assignment and weapons loading would be done next, and the work by Shops 3 and 4 and the refueling would be done last. In general it would seem advisable to defer final mission assignment and munitions selection as much as practical, in order to permit those decisions to be made with the most current information possible.

A special control variable is provided to facilitate a separation between fueling and the rearming operations. If NOFUEL is initialized as unity, these operations will not be accomplished at the same time; this constraint overrides any contradictory rule implied by the shop sequence listing.

Management of the preflight maintenance tasks is facilitated by a flag that is maintained for each aircraft in the 16th position of aircraft array--i.e., in ACN(-,16). The flag may be set to any of 13 different positions, defined as follows:

Preflight Flag ACN(-,16)	Value when Refueling is: Not in Process	In Process
Prefight tasks (shop #26) have not been initiated	1	8
Preflight delay is in process	2	Not permitted
Delay (shop #26) complete; awaiting assignment, or assigned but awaiting 2nd of shop #27 subtasks	3	10
Reconfiguration (shop #27) is in process (one or two subtasks)	4	11
Reconfiguration (shop #27) complete; one subtask of shop #28 may be complete	5	12
Munitions loading (shop #28) is in process (one or two subtasks)	6	13
Preflight tasks complete	7	14

As can be noted, refueling (or any other task) may not be carried out during the preflight delay.

1. MANAGEMENT OF PREFLIGHT TASKS

Preflight tasks are managed by subroutine PREFLT in much the same manner as subroutine RUNAC manages unscheduled maintenance tasks. When tasks for shop 26 or shop 29 are first identified in RUNAC, control is immediately transferred to the entry point PRFLT at the approximate mid-point of subroutine PREFLT. Unless the munitions related tasks (task 26 et al.) are to be delayed, or another maintenance task is in process, the preflight delay is initiated and the preflight flag is updated before control is returned to RUNAC. If the delay may not be initiated, the task is stored in the wait queue associated with shop 26.

When the preflight delay is concluded, MANAGE transfers control to RUNAC at RUNAC2, and control is immediately passed to the beginning of the PREFLT subroutine, where the termination of preflight tasks is managed. The procedure for terminating the other preflight tasks is

similar, except that RUNAC is called so that the resources may first be released by ENDTSK; that subroutine, in turn, attempts to reassign the resources using subroutine DOWPRE (do waiting preflight tasks), which fills much the same function as subroutine CHECK does for unscheduled maintenance. The primary differences between DOWPRE and CHECK are that the former first checks to see that both subtasks of the reconfiguration and uploading tasks are complete before reassigning personnel and equipment, and it does not have any equivalent to the parts repair sections of CHECK.

When control is returned to subroutine PREFLT, an attempt is made to initiate the next preflight task unless the preceding task has not been fully completed. Four distinct subroutines are used to handle aircraft assignment (ASSIGN), reconfiguration (RECNFG), munitions loading (UPLOAD), and refueling (REFUEL) tasks, because of the distinctive characteristics associated with each task. These subroutines are called in the appropriate order by subroutine PREFLT and by subroutine DOWPRE when preflight tasks have had to wait.

2. MISSION ASSIGNMENT

As soon as the preflight delay is completed the final mission assignment for the aircraft is made using subroutine ASSIGN. The scheduled ready-to-fly time is first interpreted in terms of the 16 time blocks into which the periodic estimates of aircraft supply and sortie demand are divided. The highest outstanding priority demand for the mission for which the aircraft had been designated at the time of the post-flight inspection is then identified. The process by which this is

done is first to identify the aircraft's lowest permissible assignment priority, the maximum number of aircraft that are expected to be ready, and the maximum number of aircraft to be assigned at that priority level using data generated by the look-ahead planning process described in Section V). Next, the requirements for alert aircraft, and then the requirements for scheduled flights, are each checked from the highest priority level to the lowest permissible level. The aircraft is assigned to the highest priority demand that has not already been filled.

If the aircraft is not assigned by this procedure to the mission for which it was designated, a check is made to see which other missions the aircraft could be readied for, taking into account whatever maintenance has been deferred. The procedure just described is followed for whatever other missions the aircraft is able to fly, until the aircraft is assigned. If it still has not been assigned to an alert force or a scheduled flight, it is committed to the mission to which it was tentatively assigned during the postflight inspection and is associated with the other spare aircraft configured for that mission.

In the event the aircraft had returned from its previous mission with its munitions on board, and it is assigned to a different mission, the munitions are returned to stock without any specific delay or requirement for personnel or equipment. Since the new mission will probably require that the aircraft be reconfigured, it is assumed, in effect, that the munitions downloading is a part of the reconfiguration.

3. AIRCRAFT RECONFIGURATION

After an aircraft has had its next mission assigned, subroutine RECNFG (reconfigure) is called to check whether the various racks and pylons, etc. (TRAP) with which the aircraft was equipped for the previous mission are appropriate for the next mission. If not, they must be removed and the aircraft must be reconfigured.

Before explaining those procedures, we will first review how the appropriate weapons load is determined. For each aircraft-mission combination, the user may specify up to five different standard combat loadings (SCLs); these should be ordered with the most desired munitions first. The characteristics of an SCL include an aircraft configuration (a number corresponding to the entries in the CONFIG requirements array), and one or two sets of munitions, each with a specified requirement for personnel, equipment , and time. Each configuration, in turn, is characterized by one or two sets of TRAP, each with its requirements for personnel, equipment, and time. As with such descriptors in the other kinds of tasks, any of these requirements may be satisfied with a null entry; if, for example, the same crew using the same equipment loads two sets of TRAP in sequence, the descriptors for the second reconfiguration task could be limited to the TRAP, with null entries for personnel, equipment, and time.

In determining whether a reconfiguration is required and what the new configuration should be, subroutine RECNFG checks first on the configuration of the SCL that is preferred for the assigned mission. A check is first made on the status of the munitions shop if that facility has been specified as an essential resource. If that constraint is

satisfied the munitions stocks are checked next. Only then is a check made to see whether the specified configuration is the same as or different from the aircraft's current configuration. If it is different a check is made to see if either of the two sets of TRAP is common to the two configurations; if so, it is presumed that they will not need to be changed. When the new TRAP requirements are established a check is made of their on-base stock levels. If either the munitions or the TRAP required for reconfiguration are not available, the next best SCL is checked. If these resources are insufficient for all SCLs, the task must wait. The task must also wait when there are sufficient of these resources for an SCL, but insufficient personnel and equipment. Cross-trained personnel may be substituted for the normal personnel requirement on those tasks and bases that are specified. When all resources are available the appropriate munitions and TRAP are withdrawn from stock, and the time for the reconfiguration task is computed on the assumption that it will take the same amount of time to download a set of TRAP as is required to upload that set, but that the personnel and equipment associated with the new set of TRAP will perform the job.

4. MUNITIONS LOADING

When reconfiguration is complete subroutine UPLOAD is called to initiate the munitions loading tasks. Since the required munitions were set aside when the requirements for reconfiguration were checked, all that needs to be done is to check on the facility itself, when specified, and on the personnel and equipment required for the loading subtasks. If they are available (substitute personnel may be used when

specified) a call to ADDTSK places them in the TASKQ. If they are not available, the tasks are placed in the wait queue for the munitions shop; that queue is checked by subroutine DOWPRE whenever resources from that shop become available. If only one of the subtasks may be initiated, the other is placed in the wait queue.

5. REFUELING

Refueling is included among the preflight tasks but does not have a rigid relationship to the other preflight tasks, as they do with each other. Refueling is accomplished by Shop #29, whose position in the shop sequence list is under the user's control, as discussed earlier. Thus, it may be placed last or first, or grouped with other shops. Furthermore, the refueling task may have its own list of incompatible tasks, as does an unscheduled maintenance task. In addition, the user controls the special variable NOFUEL, which prevents fueling when any of the munitions related tasks are in process if it is initialized to unity.

Management of these restraints is handled by the PREFLT subroutine and, when necessary, by the DOWPRE subroutine. When conditions permit, subroutine REFUEL is called to process the fueling task. The only feature unique to this task is the requirement for a quantity of POL. The amount of fuel required is taken to be a characteristic of the aircraft type; the other resources required for refueling are stored in the TSKRQT array, along with those for the unscheduled maintenance tasks. When subroutine REFUEL is called, the required POL is withdrawn from stocks and the necessary personnel and equipment are assigned; if

the resources are insufficient for the basic refueling procedure, and for any alternative procedures that are listed, the task is placed in the refueling shops' wait queue. Control is returned to subroutine PREFLT.

6. MUNITIONS BUILDUP

Although munitions buildup is discussed here in connection with the other munitions related activities, it constitutes a completely distinct set of off-equipment functions that are managed independently from the aircraft related tasks in a separate set of subroutines. Resource requirements for the buildup of each type of munition are specified in much the same manner as simple parts repair jobs, but the procedures used to schedule and prioritize these assembly activities are unique to these tasks.

The periodic aircraft supply and sortie demand projections provide the basic "operations" data that drive the weapons buildup selection and prioritization logic. Immediately following that projection, subroutine MANAGE transfers control to subroutine MUNEED (munitions needed) to determine munition needs (when the control variable BUILD has been initialized to 1). A tally is first prepared for each base of the number of munitions assembly tasks that are expected to be completed within the next two hours. Another tally is made of all on-base munitions that are loaded, assembled, being assembled, or are already waiting to be assembled. Subroutine MUNEED then tabulates the sorties that are projected to be flown in terms of launch time, priority, mission, and aircraft type, on a base-by-base basis. Flight times

within the planning time-horizon are divided into four time blocks. Demands for alert aircraft are presumed to generate equivalent munitions demands in the first and third time blocks.

With these demand data, control is then transferred to CKBILD (check buildup requirements). This subroutine first converts the sortie demands into the munitions demanded by the preferred SCL for each particular mission and aircraft type and then checks whether sufficient munitions are available or committed. The checks are made first for the highest priority missions in the first time period, then for the next priority, etc. Following that, the demands in the second time block are checked, etc. Whenever sufficient munitions are not available or have not been scheduled to be built, a weapons buildup task is defined--if sufficient unassembled munitions are available--and control is transferred to subroutine DOBILD where the required personnel and equipment are checked (substitute personnel types may be designated). If tasks cannot be initiated they are placed in the wait queue in the BACKLG array, until the number waiting equals the number of tasks that are expected to be completed before the munitions requirements are checked again. If sufficient unassembled munitions are not available, the adequacy of munitions for the next lower priority SCL (for that particular mission and aircraft type) is then checked. If no munitions can be located, the demand is dropped. This process continues for all priority levels and time blocks, for each base in turn. Buildup demands generated by sorties in the third and fourth time blocks that cannot be initiated are dropped on the premise that they will be reexamined in the next two-hour review, and need not be queued at this time.

If the munitions assembly resources are not fully committed to the immediate demands, they may be used to build up a reserve; the choice of the munitions to be assembled is based on the existing supplies and the history of the demands for munitions.

When a munitions buildup task has been completed, subroutine MANAGE transfers control to the ENDBLD entry point in subroutine DOBILD where the task is removed from the BUILDQ heap, the shop pointers are updated, and the personnel and AGE are returned to stock.

When control is returned to MANAGE it is immediately transferred to the DOWBLD (do waiting build-up) entry point in subroutine DOBILD, where a check is made to see if the released resources can be used for another weapons assembly task.

VII. PARTS AND EQUIPMENT REPAIR JOBS

TSAR provides the user with features that permit the examination of a wide variety of questions related to parts stockage and parts repair policies. Indeed, a variety of questions concerning autonomous and consolidated parts repair capabilities within the theater were central in shaping TSAR's theater characteristics. In its present form, TSAR may be used without any consideration of aircraft parts, with autonomous airbase parts repair facilities, with repair in whole or part at other operating bases, with a centralized parts repair facility in the theater, or with a combination of the last three modes. The constraints imposed by faulty support equipment may also be reflected.

A specialized set of subroutines handles the several elements of the parts and equipment repair procedures. The first three of these subroutines can be used to initialize the parts stockage data and the spare-parts pipelines from CONUS to the theater, and, when there is a CIRF, between the CIRF and the operating locations. The first subroutine used for parts and equipment repair determines the appropriate administrative delay to simulate before initiating the repair process. Following that delay, other subroutines check on the availability of resources, store the repair jobs that are initiated, and conclude the repairs; another special subroutine is available to disassemble LRUs to obtain SRUs. When parts repair is done at a CIRF, other subroutines come into play. These procedures will be outlined briefly later in this section and discussed more completely in Sections X and XI.

1. INITIALIZATION OF PARTS INVENTORY AND PIPELINE DATA

Although the user may enter the initial parts inventory and pipeline data for each base, much as for the other classes of resources, he instead may elect (by initializing OUTFIT) to have those data generated as an integral part of the input and initialization process. When this option is elected (for some or all bases), the nominal quantities of parts that should be procured for each base are determined according to the standard computational procedures outlined in Chapter 11 of Air Force Manual 67-1, or, for WRSK kits, with an approximation to the cost- sensitive DO-29 procedures. For in-theater units, both POS (peacetime operating stocks) and BLSS (base level self-sufficiency stock) are assessed.[1] In their most basic form, those procedures estimate the number to be procured as the sum of (1) the expected number being repaired on the base, (2) the expected number undergoing repair off-base, and (3) an additional number to hedge against stochastic variations in the demand.

After all data have been entered, subroutines COMPRT (compute parts) and IPARTS (initialize parts) are called by subroutine WRAPUP to carry out these computations if the control variable OUTFIT is not zero. The estimates are made on the basis of (1) the parts-procurement-policy planning factors that the user enters using Card Types #23/70 and #23/72, (2) the expected daily demand rate for each part based on the

[1] The user may modify these computed stock levels to reflect stock shortages or expected battle damage, etc., by entering the additional stock with the basic Card Type #23. As now structured, 500 part types may be modified in this manner. The NRTS rate specified with these cards will override any value entered using the #23/20x or #23/30x Cards if the control variable CHNRTS is initialized to unity; a null entry on the basic #23 Cards will be interpreted as a zero NRTS rate.

task and parts-repair probability data entered with Card Types #5, #7, and #8, (3) the NRTS data entered for each part with Card Type #23/20x (and #23/30x), and (4) parts cost data entered with Card Type #23/66. If desired, the user may specify different safety stock factors for LRUs and SRUs, and for those tasks that may be deferred indefinitely and those that may not.

For units that are deployed to the theater the nominal parts allowance, or WRSK (wartime spares kit), may be computed by either of two procedures. In the first procedure the allowance is computed on the basis of 30 days supply at the planned wartime sortie rate for the RR (remove and replace) items, and the same as for BLSS for the RRR (remove, repair, and replace) items. A 30-day supply of SRUs that are not reparable is included for LRUs that are RRR; stock levels for RRR SRUs are computed in a manner analogous to the LRU computation. With the second procedure, used when the control variable PMODE is greater than zero, the WRSK allowance is computed in accordance with an empirical algorithm that approximates the cost optimization procedures used in the AF DO-29.

If the user desires to define parts shortfalls over and above those that are in the pipelines, three options are provided. In the first instance the actual number of each type of part that is procured for a base can be reduced by a fixed percentage that the user specifies with the control variable SHORT. The other features permit the user to simulate shortfalls differentially for the various part types. Either or both types of shortage may be used to simulate the parts environment that the user judges to be most realistic. The actual shortfall for

each type of part will be the expected value of the shortage if RANDM is zero, or will be drawn from a Poisson distribution if RANDM is unity. If NEWPRT is initialized, the parts initialization computations, including these considerations of shortages, are redone each trial.

The number of serviceable items on base for each part type is set equal to the number procured, minus the nominal number that would be expected to be in the pipeline. In other words, it is assumed that there are no on-base reparables. The number in the pipeline (i.e., being repaired off-base) is the largest whole integer in the value developed in the prior computation, or, if RANDM is unity, a number drawn from a Poisson distribution with a mean equal to that value. If the number estimated for the pipeline is larger than the number that had been procured (taking shortages into account), the pipeline number is either reduced to the number available, or (when ZNORS = 1) the difference is made up by removing the parts from on-base aircraft at zero time (thereby generating NMCS aircraft).

As discussed in Section V, aircraft spare parts for rear maintenance bases are either entered directly (with the basic Type #23 Cards) or, when the automatic parts generation feature is being used, they are provisioned by redistributing the spares that have been calculated for the operating bases. For tasks that must be done in the rear, all parts are placed in the rear. An estimate is also made of the fraction of the other tasks that will be accomplished at the rear base at the same time that the mandatory work is underway, and a like fraction of all parts is placed in the rear. If aircraft are also sent to the rear whenever the ready-to-fly time exceeds MNTLMT, etc., the

fraction of the parts placed in the rear can be increased by the user's specification of RPARTS.

When the user is examining CIRF operations, other considerations affect the parts initialization process. For the procurement computation the user may (1) neglect the effect of the CIRF on NRTS rates, and (2) ignore any advantages of scale in the SRU computation, or he may take one, or both, into account. These choices are controlled by the value of the control variable OUTFIT. If OUTFIT is unity, the NRTS rates that are used for computing the number of parts to be procured for each base are those that would apply if there were no CIRF; and the number of SRUs is the sum of those computed for the individual bases, even though all the LRUs may be repaired at the CIRF. This mode (OUTFIT = 1) permits the user to stock a set of bases at levels identical to those that would be estimated if there were no CIRF. If OUTFIT is set equal to 3 or 4, the procurement computation presumes those NRTS rates that apply with a CIRF (the data entered with Card Type #23 30x); if it is set equal to 2 or 4, the safety factors in the SRU procurement computations reflect the scale advantages to be expected when the demands for several bases are consolidated at a CIRF.

The authorized level of stock computed for each base assumes that all serviceable LRUs are at the operating locations. SRUs, however, are allocated in the same proportions that in-theater work is accomplished on their parent LRU. Thus, without a CIRF, all parts are at the operating bases, but when a CIRF is introduced, some of the SRUs will be at the base and some at the CIRF for LRUs that are partly repaired on-base and partly at the CIRF. When certain aircraft maintenance tasks

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must be carried out at a base in the rear, any parts used with those tasks are emplaced at the rear base; furthermore, if the user's choice of JOBCON indicates that other tasks are to be accomplished in the rear whenever the aircraft is there, the portion of the parts the are appropriate for the tasks expected to be done in the rear are also retained at the rear base.

After the nominal parts level and the available number of serviceable parts have been computed and stored for each type of part at each base, the parts pipelines are initialized. When there is no CIRF, the parts that are in the pipeline are scheduled for delivery within the user-specified order-and-ship time, with the actual day picked at random for each item. When a CIRF is assumed to be present, there will be some items in the base-CIRF-base pipelines and others in the CIRF-CONUS-CIRF pipeline. The mean numbers in each pipeline for each type of part are estimated on the basis of the user-supplied data regarding the various times and the daily demands generated at the operating bases. Items are then positioned in both pipelines for delivery after the simulation is begun.

2. INITIALIZATION OF STOCKS FOR BATTLE DAMAGE REPAIRS

Parts also may be stocked automatically for repairing battle damage sustained in air operations. The quantities stocked at each base are based on a specified number of sorties for each of a specified number of aircraft, and on the battle damage rate expected, on the average, during the first 30 days of conflict (assuming the various mission types are flown equally). The number of aircraft is the initial number on base,

or, when OUTFIT is not zero, the number of aircraft specified for the spares stockage algorithms. The number of sorties is entered with Card Type #15/2.

If the condemnation rate for parts removed in connection with battle damage repair is unity, the NRTS rate is immaterial. However, if all parts are not condemned, the NRTS rate specified for the same part in connection with normal unscheduled maintenance will be applied. If the same part type does not occur in connection with a regular unscheduled maintenance task, it is then necessary to specify the appropriate NRTS rate with a standard Type #23/20x or #23/30x Card. However, if the quantities are subsequently changed, using a normal Type #23 Card, the NRTS rate entered therewith will prevail for the simulation if CHNRTS is unity.

The stocks of these battle-damage spares that are allocated to the various operating bases, take into account any task specifications that mandate that the task be accomplished at a rear base. The allocation also takes into account (at least approximately) the likelihood that some tasks normally done at the operating base will actually be cleaned up when an aircraft is in the rear for mandatory rear-area maintenance.

3. ON-BASE PARTS REPAIR

Whenever an attempt is made to initiate an on-equipment task and a faulty part is found, (or a faulty SRU is found during the repair of an LRU), parts that are never repaired on-base may be NRTSed immediately; otherwise parts are set aside for a delay time before the actual repair

process may be initiated.[2] The delay is determined in subroutine ADMIN and is equal to the sum of the mean time for the on-equipment task (to simulate the time for removal) and an administrative delay. (The user specifies the mean and distribution for this delay by shop and by base, using Card Type #47). When that delay is completed, the NEWREP (new repair) entry point in the INIREP (initiate repair) subroutine is called. (If the variable EXPEDite is initialized, and there are no serviceable parts of the required type, the administrative delay is reduced by 1/EXPED, or to zero if EXPED exceeds 10. This feature permits the user to simulate an organization in which the time required to process a reparable can be expedited when necessary.)

When the entry NEWREP is called, a check is first made to see whether the part will have to be repaired elsewhere (is to be NRTSed), or whether it can be repaired on base; this is done by comparing a random number with the NRTS rate. The resources required for the repair process are determined next. One or more procedures may be specified for each type of part: The first is assumed to apply when it is determined that the part is to be NRTSed, unless it was NRTSed immediately on removal from the craft. If the part is to be repaired on-base and has two or more possible repair procedures, the identity of the required procedure is determined with a random number using the data provided as to the relative likelihood that one or another of the procedures is required. Each parts repair procedure can specify requirements for a number of one type of specialist, one or two types of

[2] If the NRTS rate for a part, LRU, or SRU is 101, it is shipped immediately upon removal from the aircraft (or from the LRU); if the rate is from 1 to 100, any decision to ship the unit is made after an administrative delay.

equipment (including a particular AIS station), and time; if the part is an LRU that may have a defective SRU, each SRU is specified by including it as an additional requirement in an LRU repair procedure.

The next step is to check whether the shop has been closed by air attack and, if not, whether the necessary personnel[3] and equipments are available. If they are not, the repair must wait; when the resources are available, parts that are to be NRTSed are consigned for shipment with a call to subroutine NRTSIT, and the required personnel and equipment are committed for the specified time (the timing error in dispatching the part before the time has expired is neglected for convenience in coding).

If the part is to be repaired on-base and an SRU is defective, the faulty SRU is withdrawn and placed in a two hour administrative delay. Then checks are made to see if a serviceable SRU is in stock. If none are available and an aircraft is NORS for the LRU, the user may specify (by setting CANSRU > 0) that another LRU of the same type may be sought in the wait queue, and disassembled to obtain its serviceable SRUs if it doesn't require the same SRU--i.e., it may be cross-cannibalized. Subroutine SALVAG searches the wait queue and carries out the cross-cannibalization. If the repair job still cannot be started, because of the shortage of an SRU, it is placed in the wait queue of the appropriate shop. If the user has specified that jobs that must wait are to be prioritized (by initializing ORDWT = 1), the repair job is

[3] If the data base differentiates between flight-line specialists and back-shop repair personnel, and repairs are to be conducted at a base where the personnel are not organized in that manner, the personnel requirements are interpreted in terms of the equivalent flight-line specialist.

placed in the wait queue (using subroutine WAIT) according to the value of the variable TIME, where TIME is defined for on-base repairs of a particular type of part as:

TIME = - 1000 × A × I/T where "holes" do exist

or

TIME = 10 × (1 + S) × MTBF/I if no aircraft require the part

where S = Number of serviceable parts of this type on-base

MTBF = Mean time between failures of this type of part

A = Number of aircraft that lack this part

T = Mean repair time for this part

I = Measure of importance; proportional to the total number of mission types for which part is critical

When resources become available, the part with the numerically lowest value of TIME will receive priority. As an examination will indicate, these relationships place the greatest emphasis on the most needed repairs that can be accomplished most quickly; or, if no parts are in immediate demand, the emphasis is placed on important parts that are most likely to be required next. Other algorithms could easily be inserted at this point in the code, if the user prefers to consider a different set of rules. (The numerical constants in these equations are simply scale factors that help maintain distinctions between the integer values of TIME.)

When the necessary resources are at hand to initiate the job, subroutine DOREP (do repair) is called and the repair job is entered in the time heap associated with the REPQ array. If the part for which the

resources have been committed is NRTS, the repair job is flagged by specifying the negative value of the repair procedure. The DOREP subroutine is also used when it is necessary to interrupt an on-going repair job. When that occurs the job is transferred from the REPQ array to the INTTSK array, the SHOPS array pointers are updated, and the personnel and equipment that had been engaged are released. A special provision is included to deal with the problem of terminating a repair for which the part itself was destroyed during an airbase attack.

The INIREP subroutine is also used when resources are released and an attempt is made to start parts repair jobs that have been interrupted or are waiting. The resource requirements are checked, and if the job can now be started, the INIREP subroutine updates the various pointer systems related with the INTTSK, WAITSK, and SHOPS arrays.

When the administrative delay for an SRU is completed, entry NEWREP is called and checks are made to see whether it is to be NRTSed or whether it may be repaired on-base, much as for an LRU. Checks are next made to see if the required personnel and equipment are available to start the repair procedure. If they are not, the repair must wait; if they are, the the SRU is NRTSed, when appropriate and the personnel and equipment committed for the specified time; again much as for the LRU.

When a parts repair job has been completed, control is transferred from subroutine MANAGE to subroutine RUNSHP (run shop). The part or rebuilt LRU is put into stock, and subroutine ENDREP is called to release the personnel and equipment and to update the pointer systems used with the REPQ and SHOPS arrays. Unless the special parts disposition logic (see Section XI) is applicable (i.e. unless SHPREP >

1), the repaired part is retained if it was removed on base or returned to the base where it was removed. When it is retained on base, and when there are aircraft on base that require a part, subroutine CHECK is called when control returns to RUNSHP. If an aircraft is still waiting for the part, the appropriate on-equipment task is initiated. When the part was not removed on base, or if the special parts disposition logic selects another base, the part is shipped to the appropriate base. Similarly, when an SRU repair is completed, resources are sought to repair an LRU requiring that SRU. When control again returns to RUNSHP, subroutine CHECK is called again with the shop number to be sure that the newly released personnel and AGE are reassigned if they are needed.

4. OFF-BASE PARTS REPAIR

When a faulty part is found to be NRTS, a check is made as to where it is to be shipped for repair. Based on the data supplied by the user with Card Types #34, different destinations may be specified for each type of part, subject to the data limitations outlined for that Card Type in Section XII. If there is a central repair facility in the theater, TSAR assigns it the base number MAXB. If a part is to be NRTSed to a depot outside the theater, the destination should be entered as (MAXB+1)--i.e., one greater than the largest number of bases.

For RR items (an item with NRTS = 100) an option has been provided to permit the nominal shipping instructions to be overridden when the number of serviceable LRUs falls below a specified percentage (ADAPTR) of the base's initial number of LRUs. When this occurs, the list of

bases specified for lateral resupply is checked to find a location that is able to repair the item (NRTS < 100) and has an undamaged shop. This option can be used, for example, to simulate an adaptive parts repair doctrine that discontinues reparable shipments to the depot and attempts to accomplish the repair in-theater, when parts stocks are low.

A faulty part may also be shipped to another operating base, even though it would not normally be NRTSed, when the shop in which the repair must be done has been closed by damage from airbase attack. When this occurs the lateral resupply base list is checked for a base with the shop open and the NRTS rate for the part in question lower; if a base is found, the part is shipped to that base if the two-way shipment time is within one day of the reconstitution time for the damaged shop.

If the part is shipped to another operating base for repair, the part is treated just like any other job generated at that base and begins by undergoing an administrative delay. The number of the originating base is preserved so that the part may be returned when repairs have been completed if the special parts disposition logic is inoperative. Depending upon the NRTS rate for that type of part at the receiving base, the part could be shipped to yet another base; if it is repaired at that base, it will be shipped back directly to the originating base when repairs are completed, unless the disposition logic is operative and selects a different destination. It is left to the user to design the Card Type #34 inputs such that a faulty part will not be NRTSed from one base to another until it arrives at the originating base.

If a part is condemned, or is shipped out of the theater, its replacement, when one is specified, is consigned for delivery directly to the base of origin, even though a CIRF may be operating, unless the control variable CONSIG is initialized to unity. In the latter case, all parts returned from CONUS are consigned to the CIRF for transshipment according to the user-specified theater resource management algorithms.

When a reparable is shipped to a centralized intermediate repair facility in the theater it is subjected to an administrative delay, but is then managed by a different set of rules that govern the priority it receives and its disposition when the repair action is completed. These will be outlined fully in Section XI after the properties of the transportation and information nets used in connection with these operations are explained in Section X. Parts repair times at a CIRF can be modified by the user to account for the different working conditions, using Card Type #48; this modification can be controlled on a shop-by-shop basis.

5. SUPPORT EQUIPMENT REPAIR

Many special kinds of support equipment are needed for the specialized jobs that must be conducted on a modern military airbase. And most of these equipments are both complex and expensive; malfunctions are fairly frequent and the maintenance and repair of these equipments constitute an essential set of activities. Such malfunctions and the repair of faulty equipment may also be simulated in TSAR.

Support equipment repairs are handled in much the same way as spare part repairs, and with many of the same subroutines and procedures. However, two quite different representations of equipment failure and repair are provided by TSAR. The simpler representation is used for all equipments other than the AIS--Avionics Intermediate Shops--those complex test equipments that are used to test and repair avionics on late model aircraft. The basic distinction is that in the simpler representation, equipments are either serviceable, or they are not; AIS equipment may be partially mission capable as well. Both representations are described below.

Equipment Repairs Other than AIS Sets

Whenever a task that has used support equipment (other than an AIS set) has been completed, each item of equipment is checked to see if it needs maintenance by comparing a random number with the probability that that type of equipment will require maintenance following a job. If maintenance is required, the equipment first undergoes an administrative delay, much as for spare parts, although the length of such delays is different than for parts. When that administrative delay is completed, the attempt to initiate the repair is processed in the same subroutines as a faulty aircraft part. As with parts, each type of equipment is associated with a particular shop, and the repair procedure may either be specific or be chosen at random from among a set of alternative procedures. Equipment repair procedures specify a type and number of personnel, one or two pieces of repair equipment, and a duration; and, as with other kinds of simulated tasks, alternative procedures may be

specified for consideration when the normal resources are not available. But these specifications do not include the spare parts that might be needed to repair the equipment; such problems can be approximated, however, by specifying that equipment repairs can be carried out without delay for parts on some occasions, while on other occasions are subjected to a delay equivalent to the order and ship time for spares.

If resources are available when an equipment repair is first attempted, the resources are assigned to the repair, the completion time is established, and the job is placed in the repair queue, REPQ; if resources are not available, the job must wait. Equipment repairs that must wait currently are treated in a first-in, first-out or FIFO priority; if equipment and parts are competing for the same repair personnel and/or equipment, the equipment repairs are given priority over spare parts for which serviceables are available, but must follow the repairs for parts needed for work on aircraft. As currently structured, all equipment repairs are performed on-base; equipments are not NRTSed to other bases.

Simulation of AIS Maintenance and Repair

The specialized support equipment used for testing and repairing avionics on late model aircraft--the AIS or Avionics Intermediate Shops--also may be simulated in TSAR. A full "string" of AIS will normally have several different complex electronic test equipments, or "stations," and each type of station is used for testing several different LRUs. Each station is composed of many hundreds (thousands) of sub-modules, and these stations are themselves subject to various

malfunctions that can require substantial maintenance. Furthermore, when any of the numerous low-failure-rate (and therefore unstocked) AIS parts fails, it is necessary to order one from another location, and that station will then be able to test only some portion of its normal LRUs. Thus a station will be in one of three states: fully mission capable, partially mission capable, or inoperative. If two or more stations of the same type are available, partial mission capability generally can be minimized by consolidating all missing parts at one station.

The manner is which these characteristics are modeled in TSAR is adapted another project at Rand.[4] Whenever an AIS station is used to repair an LRU or SRU, the nominal part repair time is increased to allow for maintenance of the station itself. Since such maintenance may actually occur either before or after, or even during the repair of the part, it is assumed that the part is not released until the overall job is completed. When that time is over, the LRU is released for use and a check is made to see if any piece part needed for maintenance on the AIS was not in stock. If so, the station's residual capability to repair LRUs is estimated on the basis of statistics that indicate how frequently each particular LRU repair capability is lost, on the average, when an AIS part is back-ordered. To do this we imagine that each station is divided into a number of sections, or "trays," one tray for each type of LRU, and when a part is back-ordered the mission capability of each tray is determined on the basis of the statistical experience.

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[4] Publication in preparation by G. Gebman and H. Shulman.

During the simulation, a check is made following each LRU repair to see whether during maintenance on the AIS station it was found to need a part that is not in stock. If one is needed, but there are two or more stations of that type on the base, it is assumed that the needed part will be cannibalized from another station, if necessary, and that all missing parts are consolidated at one of the stations. Thus, when an AIS part fails at any station, checks are made for each LRU tray associated with that type of station and a list is generated of all LRUs that cannot be repaired until the needed part is obtained. A sample is then drawn from the user-specified order-and-ship-time distribution, and the appropriate receipt time is entered in the LIMBO array; not until that time occurs is the capability restored for repairing those LRUs.

As will be noted, there are no specific repair procedures or specific personnel or equipment used to repair AIS equipments. Instead, the repair time of each part that is processed is increased to account for AIS maintenance, and AIS repair capabilities are probabilistically curtailed to simulate a shortage of parts to repair the AIS.

VIII. AIRCRAFT SORTIE DEMAND AND AIRCREW MANAGEMENT

The ultimate objective of an airbase is to provide combat capable aircraft at the time that they are required, and a base's capability for meeting that objective can depend importantly upon the pattern of the demand. In TSAR, that demand pattern is controlled by the user's input data and the user is provided sufficient options that most plausible requirements should be readily simulated.

A demand for a flight of aircraft specifies the type of aircraft, the mission, the mission's priority, and, normally, the base; it also specifies the number of aircraft to be launched (and the minimum acceptable number), the time they are to be launched, the time that the airbase is informed of the demand, and the recovery base. If desired, the user may also specify that a specified number of aircraft will be maintained on alert at a particular base for unscheduled demands. In addition, he may define a composite flight, made up of several sets of aircraft, or flights, each with a differing configuration, as would be required, for example, for representing coordinated attacks by defense suppression aircraft, CAP, and CAS aircraft.

Except for composite flights and specified alert forces, it is not mandatory that the launch base be specified. If the control variables "STATE" and "SELECT" are both greater than unity, a daily estimate is made of each base's sortie generation capabilities, and these estimates are used to designate a base for any sortie demands for which a base has not been specified. However, since TSAR does not include geographic concepts, such selections are not constrained by range-to-target considerations.

For user convenience the demand data may be stated either on a day to day basis or in terms of demands that recur each day with a stipulated probability (or any combination of these techniques). For the recurring demands (the periodic demands) the launch time may be entered as a precise time or as a time block; when a time block is specified, the program picks a time at random from within the block. Furthermore, a number of such flights (up to 32) may be specified with the same entry; when this is done, the launch time of each flight is selected at random from the time block. With these features a few entries suffice to represent a rich and varied pattern of flight demands.

1. GENERATING SORTIE DEMAND DATA

The initial day's sortie demands are entered before the simulation begins. They are entered after all other data are input and after subroutine INLIST has provided whatever listings of input data were requested. Subroutine READFT (read flight data) reads and organizes these data with the assistance of subroutine SORT, which orders the flights by their specified launch times and manages the pointer system used with the FLTRQT (flight requirements) array. If the launch base has not been specified for any of the sorties demanded, subroutine FRAG is called to select the base best able to fulfill the demand, the one with the lowest current level of demand relative to its estimated sortie generation capabilities. When all data have been entered, flights with common characteristics (launch base, aircraft type, mission, and

priority) are interconnected with the pointer system associated with the PTZ array.

The sortie demands for the next day and for subsequent days are also managed in the READFT subroutine. These demands are reexamined each evening at 2000 simulated time when this subroutine is called by subroutine MANAGE. If the user wishes to specify new flights or to change specifications for alert forces or periodic flights, these data are read at this time. If there is no new information, the following day's demands are based on the periodic flight demands or other flight data submitted earlier. As before, any flight demands for which a base has not been specified have a base chosen with the FRAG subroutine, using updated estimates of the bases' sortie generation capabilities, which are created daily at 1930 by subroutine BASCAP (base capabilities).

If, when the sortie demands are organized for the following day, an airbase is out of operation because its runway is closed, the demands on that base may be reassigned. If the runway is projected to remain closed for any part of the following day, and other bases have aircraft of the type specified, those demands that are required to be met before the runway is to open are reassigned either by subroutine FRAG, just as though the launch base had not been specified, or, if SELECT is zero, in proportion to the numbers of aircraft on base. Demands to be met after the runway is scheduled to be opened are not reassigned.

Provisions have also been made for entering endogenously generated flight demand data. These provisions would be used if and when the resource management logic is expanded to permit endogenous decisions

regarding sortie demands. Such a decision would be communicated by calling the entry point SORTIE in the READFT subroutine where the flight would be entered into the sortie demand pattern. If the base is not specified, subroutine FRAG selects the base best able to fill the demand.

2. LAUNCHING THE AIRCRAFT

When the time specified for launching aircraft occurs, subroutine MANAGE transfers control to subroutine FLIGHT. After checking that the flight need not be canceled because of weather conditions or runway damage, a check is made to see if aircraft have been assigned for a scheduled flight, or are available in the alert force when the demand is unannounced. Each aircraft is checked to see if it has actually been readied for flight. A check is also made for each aircraft to see that its access to the runway is not prohibited by bomb damage to the taxiways. This is done by comparing a random number to the probability that the runway is accessible as discussed in Section IX. The user can define this probability as a non-linear function of the amount of damage (the value of the access probability is initialized in the base damage and reconstruction routines and updated periodically in subroutine MANAGE). If aircrews are to be accounted for, subroutine FLYERS is called to locate a crew that is then tentatively assigned to the aircraft.

If fewer than the required number of aircraft are ready among those assigned to meet the specific demand, and if the demand has a priority at least equal to the minimum permissible level (as defined in Section

IV), the spare forces, later flights of the same or lower priority, and alert forces of lower priority are each checked in turn for a ready aircraft of the appropriate type and mission configuration. If, after all these sources are checked, the number of aircraft available to meet the demand is less than the minimum permissible number, the assigned aircraft and then the spare aircraft are checked to see if aircraft are available that will be ready within whatever time is allowed for late takeoff for aircraft of that type on that mission. If the minimum permissible number of aircraft have still not been located, the flight is canceled. If their number is sufficient, they are launched with a call to subroutine LAUNCH that updates all the appropriate tallies and pointers.

Certain additional complexities will be noted in the FLIGHT and LAUNCH routines as a consequence of the options for composite flights and for late takeoffs. When the minimum forces must be found for each of several different flight demands to prevent all from being canceled, it is necessary to withhold all launches until all flights have been checked. Furthermore, if, after checking several flights, it is found that at least one cannot be satisfied, it is necessary to modify various aircraft assignments and to release all tentatively assigned air crews. Similarly, when an aircraft is going to be launched late, it is necessary that certain data be retained until that time. To facilitate the latter operation the aircraft is placed in the aircraft delay heap until one TSAR time unit after the aircraft's expected ready-to-fly time; if it is still not ready to fly at that time, the sortie is canceled.

As each aircraft is launched it is checked for an air abort; if one is to occur, the aircraft is scheduled to land with a full load of munitions at the launching base after a six minute flight. It is handled like any other aircraft in the ensuing postflight inspection except that munitions are not required and attrition and battle damage are not assessed. If an aircraft is designated to recover at a different base, that bookkeeping is also accomplished at the time that the aircraft is launched. The actual launch is accomplished by placing the aircraft in the aircraft delay heap with the appropriate landing time. The flight times for each aircraft in a flight are determined independently, unless recovery as a unit has been specified on Card Type #16 for that type of aircraft and mission.

3. AIRCREW MANAGEMENT

TSAR's provisions for accounting for aircrews are controlled by the control variable CREWS; when initialized to 1, these features are activated.

Aircrew members are accounted for on an individual basis, much like aircraft. Each aircrew is qualified for only one type of aircraft. Their assignments are managed so that each crew will receive a specified minimum amount of uninterrupted sleep during each 24 hour period and a specified minimum rest between sorties. These two times are specified with the control variables SLEEP and REST. To avoid unnecessarily long shifts and early exhaustion it is presumed that aircrew assignments can be managed such that they remain off-duty until they are needed and will retire early whenever the demand permits.

Aircrew management is accomplished with data that are stored in the PILOTS and PILOT arrays. PILOTS maintains a record of the number of aircrews on base, and pointers to the first and the last of those crew members who are on-duty and off-duty; these data are maintained separately for each aircraft type on each airbase. The PILOT array maintains status information on individual aircrews, and pointers to the other crews with the same duty status.

The several operations required for aircrew management are carried out by different sections of the FLYERS subroutine. An aircrew is located for a tentative assignment by calling the entry point GETPLT (get pilot); or SAVPLT (save pilot), for a late takeoff. When the aircraft is launched the assignment is finalized with a call to the entry point FLYAC. When the sortie has been completed, crew data are updated with a call to LANDAC; if the aircraft is recovered at a different base, the pilot "billeting" is rearranged at that time. If the crew is due for a sleep period they are placed off-duty; if the aircraft was lost, but the aircrew was not, it is assumed that the crew cannot be reassigned for a minimum of four days.

In addition to these operations, entry point RELIEF is called at two hour intervals by MANAGE to check the on-duty crews and to relieve them as required. When the airbase has been attacked and the user has specified that a portion of the on-base aircrews are lost, subroutine DISABL is called by subroutine BOMB to inflict the losses and update the aircrew information.

IX. AIRBASE ATTACK AND RECOVERY

The most serious disruption that an airbase can experience is undoubtedly that associated with a heavy airbase attack. Previous estimates of the damage likely to be sustained during such attacks on our NATO airbases and the lack of any generally agreed upon estimate of the real effects of such attacks on a base's capabilities to recover and generate useful aircraft sorties were prime motivations for TSAR's development. And the highly irregular damage patterns experienced on bases that are subjected to conventional attack contributed importantly to the decision to create a model with sufficient detail that the critical effects of the highly stochastic damage patterns could be captured. Unless the possibilities for bottlenecks as well as for emergency and alternative procedures were included, the probable behavior of an airbase during the crisis following an attack could hardly hope to be represented.

1. SPECIFICATION OF ATTACK CHARACTERISTICS

In TSAR, airbases are attacked and resources are damaged or destroyed in accordance with the specifications supplied by the user on the basis of independent damage calculations. The user is free to schedule attacks at whatever times and bases he chooses, and TSAR has been structured to accept fairly highly detailed damage data. These data are entered at the beginning of the simulation and the scheduled attack times are placed into the heap in the ATTACK array; the various damage data are stored in compact form in the DAMAGE array.

The damage data supplied by the user for each attack may specify the percentage damage sustained by each type of each of the 11 classes of resources. For aircraft and facilities, the percentage damage sustained by the ground personnel, equipment, and parts associated with the aircraft or facility at the time of the attack, may also be specified independently for each of those resource classes. If the user would prefer to simplify the input process for one or another class of resource, he can omit the type specification and all types of the specified resource class will sustain the same percentage loss.[1] This aid is available for all resource classes except aircrews, shelters, and facilities; for aircrews and shelters it is unnecessary since they are all treated alike, and each facility or building must be designated specifically.

A special version of the AIDA (Airbase Damage Assessment) [2] model has been developed to provide these data for TSAR. Dubbed TSARINA, for TSAR INputs using Aida, this new computer model accepts detailed descriptions of the location, construction, and contents of various airbase facilities, as well as detailed specifications of an enemy attack and weapons effectiveness factors, and converts the resultant Monte Carlo damage estimates into the format required by TSAR.

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[1] Alternatively he can specify separately the expected damage to as many as 50 particular types of a resource class, and also separately specify the percentage loss of all other types of that class. This mixed option has specific requirements for the order the data are entered that are satisfied automatically if TSARINA has been used to generate the damage data.

[2] D. E. Emerson, "TSARINA--User's Guide to a Computer Model for Damage Assessment of Complex Airbase Targets," The Rand Corporation, N-1460-AF, August 1980.

TSARINA permits damage assessments of attacks on an airbase complex composed of up to 500 individual targets (building, taxiways, etc.), and 1000 packets of resources. The targets may be grouped into 20 different vulnerability categories, and many different types of personnel, equipment, munitions, spare parts, TRAP, and building materials can be distinguished. The attacks may involve as many as 50 weapon-delivery passes and 10 types of weapons. Both point-impact weapons (such as general-purpose bombs and precision-guided munitions) and area weapons (such as cluster bomb units) can be accommodated.

TSARINA determines the actual impact points by Monte Carlo procedures--random selections from the appropriate error distributions. Weapons that impact within a specified distance of each target are classed as hits, and estimates of the damage to the structures and to the various classes of support resources are assessed using "cookie-cutter" weapon-effects approximations.

For each trial computation of an attack, TSARINA determines the fraction of each target covered by the circular damage patterns, and the results include estimates of the overall damage to each target and to all resource classes that are collocated with that target. In addition, the TSARINA output includes an estimate of the total percentage of each type of resource that was damaged at its various storage locations. These latter data are formatted to be loaded directly onto disk for immediate processing by TSAR, or to be stored for subsequent use; no manual data conversion is required.

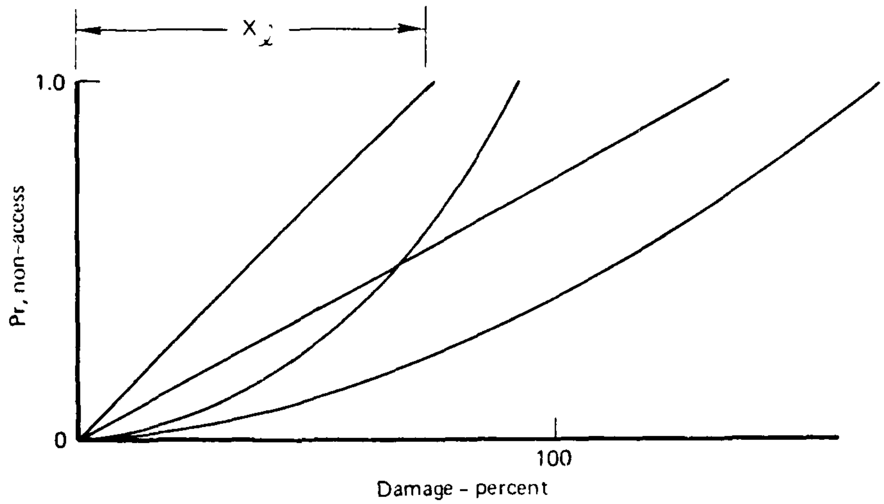
2. EFFECTS OF DAMAGE TO RUNWAYS AND TAXIWAYS

TSARINA tests to see if operations are possible from runways and other surfaces that are of sufficient size for emergency flight operations. To do this, the surfaces are searched to find if there is an undamaged area of the prescribed minimum size. This area may either be rectangular, or rectangular with a superimposed triangular clear area needed for cable clearance with a mobile aircraft arresting barrier. If no clear area can be found, the area that would require the minimum number of repairs is located and that number of repairs is reported to TSAR as the runway damage. In TSAR aircraft operations are prohibited until base engineers have repaired that damage.

Bomb damage to taxiways is handled quite differently. TSARINA reports the total number of craters in designated taxiways as a percentage of a user-specified number. As with runways, only a limited amount of the damage would need to be repaired to permit any aircraft to gain access to the runway from its shelter or other parking area. To fully capture the effects of such damage on the on-base mobility of aircraft, it would be necessary to develop complex network access algorithms for TSAR and to maintain more detailed shelter and taxiway data. Additional complexities would be introduced to define an optimal repair strategy that would maximize the rate at which aircraft could gain access to the available area for takeoffs and landings. Although a conceptual plan exists to achieve such a capability, time has not permitted actual development.

The current TSAR mechanism for assessing how taxiway damage affects aircraft access to the runways depends upon the user's

appreciation of the problem under analysis. The actual number of impacts on the taxiway system in a given attack are entered into TSAR as a percentage of some fixed number (MAXTAX when TSARINA is used to generate the estimate as mentioned above). The number can also be declared as the SIZE for facility #35 (i.e., the taxiway system). The user must also declare (on Card Type #17/1) how the "probability that an aircraft can gain access to the runway," varies as a function of that damage percentage. Relationships like those shown below may be represented. Damage of 100 percent would imply taxiway impacts equal in number to SIZE.



In the sketch x_i identifies the intersection of the curve with Pr = 1; permissible relationships are of the form

$$Pr = (d_i/x_i)^n$$

Here d_i is the existing damage percentage and n is an exponent. The user specifies x_i and n on Card Type #17/1 to reflect as best he can

a relationship that seems reasonable taking into account his knowledge of the attackers' presumed attack objective and the nature of the taxiway system of the airbase.

As taxiway damage is repaired the non-access probability is reduced, and that relationship may be non-linear, as would be expected, since access will generally be achievable with only a limited amount of repair. The rate at which the "damage" is reduced is controlled in the same manner as that for damage to other facilities--i.e., a delay time plus a variable amount of time based on the amount of damage as discussed below.

3. ESTIMATION OF THE STATUS OF RESOURCES AFTER THE ATTACK

When the time for an airbase attack arrives, MANAGE transfers control to subroutine B[illegible]MP that manages the subsequent operations until all of the specified damage has been dealt with, the shops and their activities reorganized as required, and the civil engineering resources allocated to high priority repairs. The base stocks of the various damaged resources are decremented first; that process is straightforward for losses to off-duty personnel, munitions, TRAP, building supplies, and the residual POL storage; it is somewhat more involved for on-duty personnel, aircrews, aircraft, aircraft shelters, and other facilities as will be described. The losses sustained by each type of each class of resource is computed separately. For all resources except aircraft and facilities (and the personnel and AGE actively engaged at the time of the attack) the losses are either determined as the expected value of the number lost or are sampled from the appropriate binomial

distribution, depending upon the value of the control variable NANUNI.

Normally only off-duty ground personnel losses are specified directly by the user; for on-duty personnel the basic TSAR logic dictates that they suffer whatever losses would be expected when the facility to which they are assigned is struck or the aircraft they are working on is damaged. The user is provided options, however, so that the casualty fractions for certain types of on-duty personnel can be specified independently of the status of the facilities. When aircrews are lost, they must be removed from the PILOT array and their pointer system reorganized; this is accomplished with a call to the DISABL subroutine. For the aircraft and the facilities it is necessary to handle the damage to whatever other resources are present, as well as the damage to the resources themselves. For resources specified by the user with the #43 Card Types, orders are placed to replace the losses sustained with special shipments; such resources arrive following the specified delay for such shipments.

Aircraft shelters may be represented in TSAR and a subset of these shelters may be designated for use by aircraft that are on alert. If there are more aircraft on base than may be sheltered, the aircraft that are unsheltered are selected at random from among the non-alert aircraft, and the remainder of the aircraft are assigned to a shelter with the alert aircraft assigned first to the alert shelters. A random number is drawn for each unsheltered aircraft and compared with the likelihood that unsheltered aircraft are damaged. Each shelter is then checked to see if an aircraft would sustain damage if the shelter door were open by comparing a random number with the damage probability for

each shelter. If there are aircraft in the shelters that are so exposed, a check is made to see if tasks are ongoing that would require the shelter door to be open; if so, the aircraft is damaged. If not, a check is made to see if the aircraft is damaged even with the doors being closed. Different damage probabilities may be considered for the alert shelters and for the other shelters. Each damaged aircraft is checked to see whether it is reparable, or whether it is suitable only for salvage. If the user has stipulated that personnel or equipment are lost, the on-equipment tasks that were ongoing at the moment of the attack are each checked and the survival of the associated personnel and equipment is determined by comparing random numbers with the specified loss rates for these resources for each aircraft that was damaged in the attack. If resources associated with the task are lost, they are eliminated. If an aircraft is not reparable, it is next checked for parts that may be cannibalized for stock; for each part on the aircraft's parts list, a random number is compared with the product (FSALVG × the specified parts loss rate) to determine whether the part survived. If it has survived it is placed into the base's stock of serviceables. The time to remove the parts is neglected on the assumption that that operation would be conducted as time permits. Only after these related resources have been checked are the aircraft records eliminated (using subroutines ENDAC and KILLAC). If the user has specified that lost aircraft are to be replaced with aircraft from CONUS or by filler aircraft that are held in reserve in the theater, subroutine ORDER is called to initiate that process.

When any of the other facilities are damaged another complex procedure must be followed. For these targets the user supplied damage data include the percentage of the facility that is damaged as well as the percentages of the personnel, equipment, and parts that are lost.[3] The first step is to temporarily store these percentage damage data.

When all the damage data have been entered, control is transferred to subroutine REORGN where the first steps are to define the status of resources present in the shop facilities damaged in the attack. The personnel and equipment that are considered to be at risk when a shop facility is hit are those engaged in parts repair jobs and those on duty at the shop and unassigned. If the user has designated that the activities of a particular shop are carried out at more than one location, the personnel and equipment that are at risk at each location are assumed to be in the same proportions as the user-specified job capacities at each previously undamaged location. Unless personnel and equipment have been assigned to individual aircraft squadrons, all on-duty unassigned personnel are assumed to be in the shop; if they have been assigned to a squadron, the flight line personnel are assumed to be in the facility numbered 30 plus the squadron number (e.g., facility #32 for the second squadron). The unassigned on-duty personnel and equipment first are checked on a type-by-type basis and those assigned to a damaged facility are decremented appropriately. To check those engaged in parts repair jobs, the shops are checked individually; for

[3] The user may exercise an option that disassociates the resource loss rates from facility damage by designating the overall loss rate for specific resource types; when this has been done, these specific rates override any resource loss rates entered with the facility damage data.

each shop hit, the off-equipment jobs are each checked and the associated resources reduced accordingly in the REPQ data. To maintain the parts records it is necessary to distinguish the parts that were being repaired at the time of the attack and those that were waiting. For the parts under repair that are not lost, the jobs are placed in the interrupted task array. The serviceable parts present in the shop and the faulty parts not being repaired are then decremented. When the repair capacity of a particular shop is distributed in more than one location, the reparable parts and faulty equipment that are being repaired or are waiting to be repaired at the time of the attack are assumed to be distributed among the undamaged locations in proportion to the capacities at the several locations. If all elements of a shop are damaged from a previous attack, the vulnerability of these resources are either zero or what they would be if the shops were undamaged (see variable ATRISK).

After the damage to the shop facilities has been processed, the surviving ground personnel are reorganized using subroutine REDPEO. If some of the personnel have been assigned to flight line units, the personnel of the same type in the several units are regrouped in the proportions implied by the "target levels" specified for each group of personnel; and then each group is divided into day and night shifts in the proportions implied by the "target" levels; this is done for all personnel types that suffered losses. Subroutine ADDAGE performs an equivalent reorganization for the equipments that survive the attack. If the user has specified an amount of time by which aircraft maintenance activities can be expected to be disrupted, all tasks still

in process on surviving aircraft, except for preflight tasks, and in undamaged shops, are extended by that amount of time (i.e., SHPDLY). If any affected aircraft had been scheduled for a late takeoff, the aircraft and crew assignments are canceled.

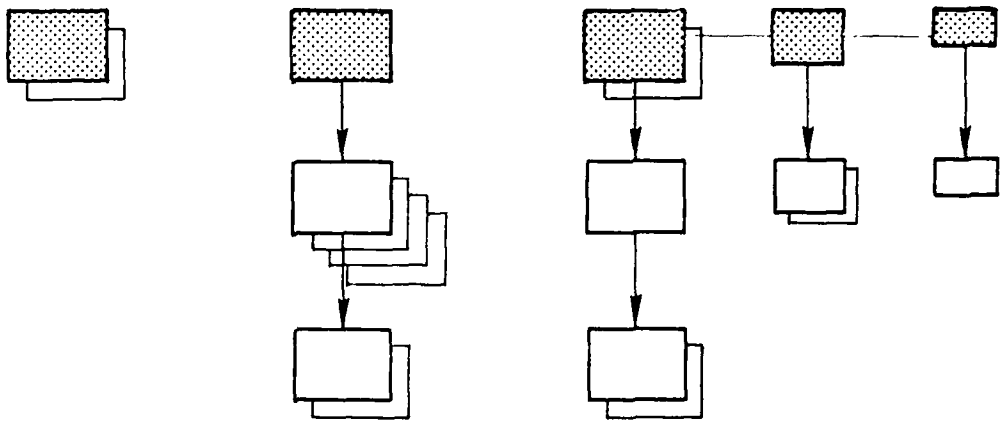
Before the damage suffered by the facilities themselves can be dealt with, it is first necessary to estimate the current status of the facilities that had been damaged in previous attacks and that are being repaired at the time of the attack. It is assumed that the percentage of the original damage that has been repaired is equal to the percentage of the repair time that has passed. When the old damage has been updated and all civil engineering resources have temporarily been returned to stock, the present damage level is estimated. It is assumed that the damages due to the prior attacks and the current attack are independent and that they combine as $D = 1 - (1 - D_1) \times (1 - D_2)$, where D_1 and D_2 are the old and the new damage fractions.

When the repair of a facility requires a sequence of procedures a check is made to see if any part of that sequence remains from a previous attack--i.e., if the facility is still undergoing repair. If it is, the amount of damage (work) remaining for each step of the procedure is determined as noted above; that is, the residual damage at the time of the attack, and that imposed by the attack, are combined as though they were independent. Unless a specific damage level is entered for a step subsequent to the first, all steps are assumed to sustain the same percentage damage.

4. POST-ATTACK RECOVERY AND RECONSTRUCTION

The actions of the base engineers and other civil engineering resources in carrying out the emergency repairs essential for restoring critical functions can also be represented with TSAR. As with any other feature of a computer simulation the representation falls short of capturing the complexities of the actual operations but nevertheless is thought to offer a considerable step forward in reflecting the grosser aspects of these tasks. Furthermore, the current formulation can be modified and improved as the community's understanding of how such a representation should be structured improves.

The optional representations of on-base facilities, and the civil engineering procedures for restoring operations at those facilities are depicted below:



"A" "B" "C"

The shaded blocks constitute actual facilities as well as repair procedures. Thus "A" depicts the situation in which the activities of a given shop are carried out in a single location and damage to that facility can be repaired using either a basic repair procedure or--the

backup blocks--one or another alternative procedure. The nature of the basic procedure is defined with the FACLTY array data for this shop, and the alternative procedures are defined by entries in the CERQTS (civil engineering requirements) array. The "B" depicts another shop whose activities also are carried in a single location, but three sequential civil engineering procedures are required to restore shop operations. Data defining each of these steps occupies a column in the FACLTY array.

Situation "C" is a distributed shop whose activities are carried out in three distinct locations, each of different size and capacity; the main location requires a three-step process to restore operations, whereas the auxiliary locations require only two steps. Each of the shaded locations must be defined in the CEPRTY array, and each of these locations and each of the subsequent procedures occupies a column of the FACLTY array.

The time for the repair or restoration of on-base facilities in TSAR is related to the amount of damage, the type of structure involved, and the numbers of civil engineering personnel and equipment that can be brought to bear on the job. Each facility considered in TSAR is distinguished by a facility number, a size, and the nature of its construction (or more correctly, the nature of the reconstruction or reconstitution required). The "facility" number is identical to the location of these descriptive data in the FACLTY array. The first 36 numbers are reserved for the reconstitution procedures to be used with the shops of the same number (and other special facilities); other locations in the array are to be used for data that describe alternative locations of distributed shops or subsequent steps in a repair process.

Thus when more than one civil engineering repair procedure is required to restore a particular facility to operational status, the descriptive data for the subsequent phases of the process are stored in otherwise unused columns of the FACLTY array. When the facility sustains damage, all steps of such a repair sequence are assumed to sustain the same percentage damage, unless a specific damage level is entered for one or more of the subsequent repair procedures. Shops (and procedures) of like number will occupy "facilities" of the same number on the different airbases. Facilities #31, #32, and #33 are reserved as assembly points for unassigned flight line personnel and equipment, when these resources have been assigned to distinct aircraft squadrons. Positions #36 and #35 in the FACLTY array are reserved for the runway and the taxiway complex. (Position #34 is reserved for a special flag that signals the time that shop activities may be reinitiated.) Locations #37 through #NOFAC are available for alternative shop locations or subsequent repair procedures.

When a building is damaged the "size" of the building and "percent damage" are combined to determine the magnitude of the restoration job. The requirements for the procedures used in repairing facilities of the differing types are filed in the CERQTS array. For each procedure some number of each of two types of civil engineering personnel and equipment may be specified. The quantities specified in the basic procedure entered for each type of structure should represent the largest sized force that can reasonably be put to work on that type of job. For most types of jobs, alternative procedures should also be included (also in the CERQTS array) so that they may be adopted when insufficient

resources are available. At this time, TSAR does not consider the reconstruction of aircraft shelters.

The time and the quantities of the (up to) two types of building materials required for each facility repair procedure are specified in terms of the requirement for one "unit" of reconstruction; the magnitude of such a "unit" is defined by the metric the user chose in specifying the "size" of the facilities of that type.

In light of the possibilities for rather highly non-linear relations between the repair time and the magnitude of the damage, the user is provided with 84 optional relationships that can be specified with a single number. The way these are used is as follows:

For each type of facility the user specifies the time required for a unit of reconstruction and a code number that defines the functional relation between total time and the magnitude of the task. If we define t as the time for a unit of construction and N as the number of units of reconstruction that are required, the total time is:

$$T = \text{Delay}(B) + t \times N^b$$

and the code number that defines this relation is:

$$C = 12 \times P + (B - 1)$$

where

$$b = g(P).$$

The function FTIME provides 12 choices for Delay(B) ranging from 0 to 48 hours (0, 1, 2, 3, 4, 6, 8, 12, 18, 24, 36, 48) and seven choices for "b" (g(P) = 0.5, 0.75, 0.9, 1.0, 1.1, 1.25, and 1,5). The code, C, that

designates the functional form, is interpreted in FTIME as:

$$P = C/12 \quad \text{the largest integer multiple of 12 in C}$$

and

$$B = C - 12 \times P + 1$$

If, for example,

$$C = 48$$

then

$$P = 4$$

$$B = 1$$

and

$$T = tN$$

that is, a linear relationship between damage and repair time, since Delay(1) = 0 and b(4) = 1.0.

When subroutines REORGN and REORG2 have established the levels of the various resources that survived the attack, and the degree to which the various facilities have been damaged, control is passed to subroutine REBILD if the user has initialized the control variable CEWORK to one (and has provided the necessary data on the reconstruction requirements). To facilitate the allocation of the civil engineering resources to repair the various damaged facilities, the user is also required to provide a priority listing of the order in which the facilities should receive attention; this list must include the locations of any distributed shops, whether or not they are to be repaired. The user also must indicate how many facilities on the list

are especially critical, by initializing the control variable CRBLDG with the facility number of the lowest priority member in the critical range. A preliminary version of such a priority list has recently been developed in USAFE; the same list is presumed to apply to all bases.

The first task carried out in subroutine REBILD is to check whether the civil engineering personnel and equipment are sufficient to initiate repairs of all damaged facilities in the critical range. If they are, subroutine INICON (initiate construction) is used to allocate the personnel and equipment and to withdraw sufficient building materials from stock to complete the job. And when the job completion time has been determined (as outlined above) these various task data are placed in the heap in the CEJOBQ array. This process continues until all damage is under repair or the resources are exhausted. To reflect the various disruptions that are not dealt with in this formulation but would delay the initiation of all reconstruction--for example, fires, and roadway damage--the computed times are all increased by the value of the control variable CEDELY (civil engineering delay).

If the civil engineering resources are insufficient to start all the critical tasks, the allocation starts with the highest priority facility that is damaged and proceeds until resources are exhausted as was just described, except that the first alternative repair procedure is used when one has been identified.

When resources are exhausted, control is returned to subroutine REORGN, and when a central repair facility has been identified, one final task must be accomplished. For each shop that was damaged in the attack a rough check is made to see if the parts could be shipped to and

from the CIRF in less time than it is projected to repair the shop; if so, the faulty parts are shipped. This last task is carried out in the subroutine SHCIRF (ship to the CIRF).

5. COMPLETION OF CIVIL ENGINEERING REPAIRS

When a civil engineering task has been completed, MANAGE transfers control to the entry point ENDCE in the subroutine BSEREP (base repair). A check is first made to see whether subsequent procedures are needed to complete the repair; if so, work is initiated as resources permit. If no additional work is required, the personnel and equipment are released, the facility status is updated, and the released resources are assigned to the highest priority task that remains. When the repaired facility is a maintenance shop the other basic task is to reinitiate the various shop activities, which is done by means of a call to the CHECK subroutine.

X. COMMUNICATIONS

TSAR allows for the representation of scheduled shipments of material from CONUS to the theater, special shipments from CONUS in response to theater requests, intra-theater shipments of resources, and the transmittal of airbase status information. The schedules for each of these types of transfers are controlled by the user's specifications, as are the contents of scheduled CONUS shipments; the contents of the other transfers are generated endogenously.

1. SCHEDULED SHIPMENTS FROM CONUS

Resources scheduled to be delivered to the theater from outside the theater after the beginning of the simulation must be specified initially by the user. These data are entered with Card Type #31; the delivery times are arranged in a time-ordered queue in the CONUS array and the cargo are stored in the CARGO array at the time of entry. The destination and time of delivery should be mentioned on the first of a set of cards when all the commodities on those cards are to arrive together.

The only resource classes that may not be shipped from CONUS are aircraft shelters and other facilities. No more than 99 units should be entered, except for munitions and TRAP, for which the limit is 2480. If more are required, enter the commodity twice for the same delivery. For POL, TSAR assumes that the unit of measure for shipments is hundreds of thousands of pounds, whereas fuel normally is stored and used in thousand pound units. (Storage capacity for POL may be enhanced by

specifying a shipment of Type #100 POL; units of measure are the same as for POL.)

When an arrival is noted in subroutine MANAGE, control is transferred to the RECSUP (receive supplies) entry point in the DOSHIP subroutine and the resources are added to the stock levels at the appropriate base. When new ground personnel, AGE, or aircraft parts arrive, subroutine CHECK is called to check whether they may be used immediately; for ground personnel, the new personnel are added to the day and night shifts to maintain the ratio of the shift sizes in the same proportions as specified by the "target" levels for each personnel type in the initializing data for each base.

When aircraft are ferried to the theater from CONUS they are added to the inventory at the appropriate base and undergo a normal postflight inspection, except that attrition is not checked. The aircrew is attached to the base's flight staff and given 24 hours to rest before their first assignment. Aircrews that are ferried to the theater (arrive without aircraft) are treated in the same manner.

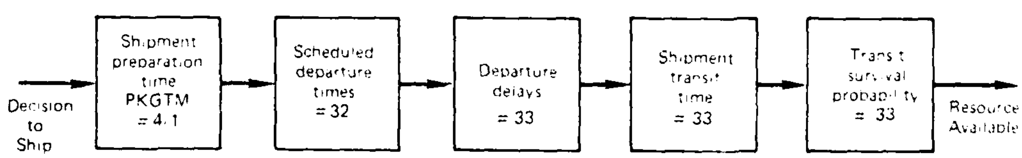
2. RESPONSIVE SHIPMENTS FROM CONUS

The user also may simulate the requisition and resupply of resources from CONUS for any class of resources except shelters and the other facilities. When activated, a requisition is submitted for resources that are lost in combat or during an airbase attack and, in the case of parts, for parts that may not be repaired in the theater. The resources requested are delivered after the delay specified by the user for each of the various resource classes. Arriving resources are

treated in a manner identical to that described in the preceding subsection.

3. INTRA-THEATER SHIPMENTS

Resources (except aircraft, aircrews, shelters, and facilities) may be transferred from one airbase to another using an intra-theater transportation system.[1] The description of this intra-theater transportation system is controlled by the user's specifications of the schedules and the statistics governing their delays, cancellations and losses. These shipments do not involve specific resources (e.g., trucks or aircraft) nor are they capacity limited; they only provide a representation of the times expended between the time that supplies are consigned for shipment and the time that a shipment reaches its destination and the cargo are added to base supplies. The algorithms governing the transfer of resources with the intra-theater transportation system are outlined in Section X-2. The factors that are considered in this representation and the Card Types that are used to input the relevant data are summarized in the following sketch.



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[1] Aircraft and aircrew transfer can be affected exogenously by specification of a different recovery base with a flight demand or endogenously by directing aircraft transfer, as discussed in Section XI-1.

The user may specify daily departure times on an individual basis for each origin-destination combination. He may also control the mean departure delay, mean in-transit time, and the distribution of these values on an individul basis, using any of the 15 distributions that may be stored in the TTIME (true time) function. By manipulating the shape of these distributions a fraction of the shipments may even be canceled;[2] the commodities that had been prepared for that shipment are then scheduled on the next shipment. The user may also specify a loss rate for the shipments between any two bases; the commodities on these shipments are not recovered.

The schedules for the various departures and arrivals are organized into time ordered queues in the SHIP array with the subroutine SCSHIP (schedule shipments). These schedules are first organized at the time the program is initialized and subsequently at midnight at whatever interval the user has specified with the control variable SHPFQ. Any of the schedules may be changed at any time during the simulation in much the same manner as the demands for aircraft sorties (see the READFT subroutine for instructions).

The data stored for each shipment include pointers to the next departure from the same base to the same destination, to the next departure from any base, and to the next arrival at any location, as well as a pointer to the location of the first package to be included with the shipment; the resources themselves are stored in the SHIPQ array.

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[2] Delays greater than 18 hours are interpreted as cancellations.

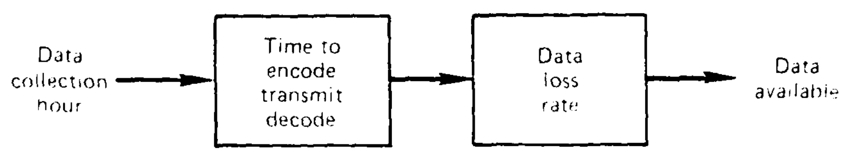
Resources are prepared for intra-theater shipment with a call to the SHPRES (ship resource) subroutine that checks on the availability of the quantity stipulated and decrements the shipper's stocks appropriately. For ground personnel, the work force is reorganized and reassigned as necessary with a call to subroutine REDPEO (reduce people). When the commodity is a faulty part rather than a serviceable part, that fact is denoted by a negative part number. When ground personnel, AGE, or serviceable parts are shipped, the numbers enroute to each base are tallied in the appropriate storage arrays for these resources; faulty parts enroute to a CIRF, similarly, are tallied in that base's portion of the PARTS array. The restrictions as to the size of the individual lots that are shipped are outlined in Section XVII. The quantities of these resources that are enroute are available for possible use in the theater resource management algorithms.

When an intra-theater departure or arrival is noted in subroutine MANAGE, control is transferred to the subroutine DOSHIP. For departures it is necessary only to update the appropriate pointers; for arrivals, processing follows the same procedures outlined for the receipt of CONUS shipments, except that provisions are also made for the receipt of faulty parts and their transfer to the appropriate on-base repair shop.

As TSAR is currently formulated, the only use made of the intra-theater shipment system is for faulty parts and for the shipment of ground personnel, AGE and equipment, and serviceable parts when imbalances are noted among the airbases by the theater resource management system outlined in the next section.

4. INTRA-THEATER RESOURCE STATUS REPORTS

Although an exact count is maintained on the status of all resources on all bases throughout the simulation and these data could provide the basis on which various theater resource management systems might be examined, it seemed inappropriate to presume that the information that would be available to such managers would be precise and up to date. Indeed, one of the greatest drawbacks associated with many centralized systems is their need for high quality communication and transportation systems. Unless some of the inefficiencies of the systems that may actually be available to our forces could be represented, it would be reasonable to question the validity of the results of any examination of schemes for managing resources on a theater-wide basis. The following sketch indicates the factors that are considered:



All necessary data are entered using the [illegible] Type Cards.

In TSAR each base may be designated to report the then current status of the ground personnel, AGE, and aircraft spare parts at several different times during the day. These data are collected at these times for transmittal to "theater headquarters"--to the theater resource manager. The user also specifies the time delay before that information would be formatted, transmitted, decoded, and available to that manager;

the delays and the distribution of those delays are controlled base by base. Since only one location is provided for "in-transit" information, the data arrival time must be no later than the next data collection time; if it is, the transit time is shortened and a report of that action is printed. The completeness of the report may be controlled in two ways; the entire report may be lost in a specified percentage of cases, or some percentage of the individual data may not be reported.

When the user elects to activate the theater communication system, the theater manager's data base is initialized with information that is accurate at zero time. However, if the user does not wish to turn control over to the theater manager until some later time he may delay the initiation of the reports by initializing OLDATA to unity. The main purpose of this feature is to avoid the related data processing during the early stages of a scenario, during which the user recognizes that resource transfers would be unnecessary or undesirable. When OLDATA is first initialized to unity and subsequently set to zero by using the special code available in subroutine CONTRL, reporting will begin when the next report is due to be sent.

The particular status reports that are transmitted when the communication system is activated are controlled by the user's choice as to which classes of resources will be managed; he may select each or any combination of the ground personnel, AGE and spare parts as explained in the next section.

Management of the theater reporting system is the function of the STATUS subroutine. This subroutine is used first to place the various transmittal and receiving times into the REPORT array heap and to

initialize the manager's data base. Subsequently this subroutine is called by MANAGE whenever a report is to be transmitted or received. The data in transit and the data on hand for theater management are stored together in the PEORPT, AGERPT, and PRTRPT arrays. The nature of this storage arrangement necessitates that reports in transit be received before the next is transmitted; it is the user's responsibility to assure that his schedules and delays make this possible.

When a report is to be received, a check is first made to see whether it was lost in transit. Subsequently a random number is drawn for each element of the data storage arrays and checked against the specified data incompletion rate. The last action in the STATUS subroutine is to store the time for the next day's transmittal or receipt of the corresponding daily report in the REPORT array heap.

XI. THEATER RESOURCE MANAGEMENT

TSAR's ability to represent operations at a set of airbases and to handle the transfer of various classes of resources among those airbases can be combined to provide a unique mechanism for pretesting policies that would exert a broad span of control over theater resources. Indeed, some may view TSAR's prime role as a test bed for examining the effectiveness of new policy proposals. Although TSAR's initial formulation is concerned only with the theater-wide management of aircraft, ground personnel, and equipment, in addition to faulty and serviceable aircraft spares, it could readily be extended to managing the other classes of resources.

The range of policy options that might be examined with TSAR is limited, obviously, to those sets of decision rules that are expressible in terms of resource status information--past, present and projected--available within this simulation. In TSAR there are basically three sets of status information available: (1) accurate data regarding current status, (2) the delayed and imperfect data provided with the theater status reporting system, and (3) an approximate projection of each base's current capability to generate sorties. In addition, a limited amount of data exist regarding future sortie demands, as well as the completion times for all ongoing tasks. The range of decisionmaking policy options that could be evaluated with TSAR should be reasonably illustrated with the following discussions of those rules that are encoded in the current formulation.

TSAR offers several options for managing aircraft resources. Initially, aircraft may fall into three different categories; aircraft assigned to an operating base, aircraft in a theater reserve of "filler" aircraft, and replacement aircraft in CONUS. If the user designates a pool of "filler" aircraft, they may be used to offset degradations due to lost aircraft or to lost and damaged aircraft, as well as aircraft with excessive maintenance requirements and aircraft that have been withdrawn to a rear base for maintenance. These fillers may be used in addition to, or instead of, a reserve of aircraft in CONUS for replacing losses. The user is provided several options as to how these aircraft are used and managed, which are discussed fully in connection with Card Type #3/2 in Section XIX. When specified, replacement aircraft are used exclusively for aircraft lost in combat or from the effects of air attack, or have been so badly damaged they must be salvaged. If the user specifies that both fillers and replacement aircraft are available at the beginning of the simulation, the losses will be replaced with a filler and the replacement will join the filler pool when it arrives in the theater if it is not then needed at the operating base.

During the simulation, decisions governing the diversion and transfer of aircraft and the assignment of sortie demands when a base has not been specified are based on the estimates of the sortie generation capabilities at the airbases that are developed each evening in the BASCAP subroutine. Aircraft that must be diverted from their assigned recovery base are sent to the base that has an open runway and the highest sortie generation capability per available aircraft. Such aircraft operate at the alternative location until the runway at their

parent base has been reopened and the base's sortie generation capability per available aircraft is within a specified percentage (MULTI1) of the capability at the alternative base.

At this time all other theater resource management rules, or algorithms, are collected for convenience in subroutines CONTRL (control), CKCIRF (check CIRF), and REPRTY (repair priority). If it were desired to substantially expand these sections, additional subordinate routines could be readily appended. The algorithms now encoded deal with the following five resource allocation decisions:

1. disposition of serviceable spare parts repaired at an operating base,
2. periodic review and reallocation of ground personnel, equipment, and aircraft spares among the operating bases,
3. acquisition of a spare part by an operating base,
4. disposition of serviceable spares at a CIRF, and
5. choice among repairs waiting at a CIRF.

In several instances the user may select from alternative sets of rules for these kinds of decisions. The choices vary in both complexity and required processing; unfortunately there is a tendency for the more complex, often more efficient rules to require the greater amount of processing, and hence to absorb greater computer resources.

The sets of decision rules that apply for any particular simulation are dictated by the initial value of the control variables SHPREP and CMODE. When SHPREP is initialized, parts repaired at an operating base

are not automatically replaced in stock or sent to the base where they were removed from an aircraft. Rather, a check is first made to see if the newly repaired part would reduce the number of NORS aircraft at the base where it was repaired, that is, whether (NORS Aircraft - Aircraft Missing Part) is less than SHPREP at that base; if so, it is retained on base. If not, all bases are checked and the part is sent to the base with the greatest need. Newly repaired parts are always considered for shipment when SHPREP is large.

The user's choice for CMODE defines the three internal control variables CTHEA, CCIRF, and SHOPRY, since CMODE = 100 × CTHEA + 10 × CCIRF + SHOPRY. CTHEA controls the classes of resources that are periodically reviewed and reallocated; CCIRF controls the treatment of an operating base's demand for a spare part and the disposition of newly repaired or newly acquired parts at a CIRF; SHOPRY controls the selection from among the parts waiting for repair at a CIRF.

The decisions and the bases for those decisions that are controlled by these three variables are outlined below. Although each set of algorithms acts independently in the manner to be outlined, there are instances in which one rule may be overridden or negated by another. An obvious example occurs when a CIRF is directed to ship all newly repaired or newly acquired spares to one of the operating bases and the operating bases are directed to order a part from central supply at the CIRF; such requests will always go unfilled if all parts have been shipped as soon as they become available. The user must be aware of the effect of his choices for the various control variables and of their possible interactions.

1. MANAGEMENT OF FILLERS, AIRCRAFT TRANSFER, AND DIVERSION

TSAR options for managing the theater's aircraft resources are designed to simulate various decisions that theater managers would, in certain circumstances, make to enhance the sortie generation potential of their aircraft force. Included would be the replacement of lost aircraft, the insertion of reserve aircraft to offset aircraft immobilized by the need for extended maintenance, and various work-leveling decisions. Such situations could arise whenever bases suffer disproportionate losses of support resources or aircraft, or when closed runways force aircraft to divert.

Management of Filler Aircraft

A pool of filler aircraft may be defined for the theater and used to offset the degradations due to lost or damaged aircraft, as well as aircraft with excessive maintenance requirements. This pool may be used in addition to, or instead of, a reserve of aircraft in CONUS. It is assumed that an air crew is available for each aircraft in the pool. The control variables FILLAC, MAXMNT, and FLEVEL provide options as to how these aircraft are used and managed.

The value for FILLAC defines the circumstances under which a filler aircraft is assigned to an operating base. The five conditions are:

FILLAC	Conditions for Filler Usage
1.	An aircraft is lost in air operations
2.	An aircraft is lost, or is transferred to a rear base for battle damage repair
3.	An aircraft is lost, or is transferred to a rear base for maintenance, including damage

4. As in 2, or when the expected repair time for an on base battle damaged aircraft exceeds MAXMNT, and the FLEVEL conditions are met (see below)
5. As in 3, or when the expected maintenance time for an on-base aircraft exceeds MAXMNT and the FLEVEL conditions are met

Whenever a filler aircraft is assigned to a combat unit to replace a combat loss, a replacement is ordered from CONUS, if stipulated by the replacement policies prescribed with the Type #43 Cards.

The value of FLEVEL affects the decision to augment on-base aircraft and controls the disposition of both aircraft repaired at a rear base and aircraft transferred from CONUS to the filler pool. To requisition an augmentee aircraft, or to return aircraft from the rear, it is necessary that the current number of on-base aircraft be less than the quantity designated by the value of FLEVEL. Those quantities are:

FLEVEL	
0	Number of aircraft less than the number of assigned aircraft
1	Number of non-battle-damaged aircraft less than the number of assigned aircraft
2	Number of aircraft less than the base's shelter capacity
3	Number of non-battle-damaged aircraft less than the base's shelter capacity

When these conditions are not met, aircraft newly repaired at a rear base and aircraft that have arrived from CONUS are consigned to the pool of filler aircraft.

Aircraft Transfer and Diversion Decisions

The basic evidence needed to reach these decisions are estimates of each base's capability to generate sorties of different kinds with the different aircraft types. Naturally one cannot expect to obtain such estimates with anything like the accuracy achieved in the simulation proper, but that simulation can only indicate the sorties that have been flown during a previous period, for a particular set of aircraft and flight demands. To obtain more general estimates a procedure has been incorporated into TSAR that provides approximate assessments of the relative airbase capabilities that are used to support such decisions. The estimates developed with this procedure are updated daily and are derived so as to capture the effects of resource shortages that result from either consumption or base damage.

The substantial processing required to develop these estimates is conducted only when the user has initialized the control variable STATE greater than zero. There are two steps in the procedure: the first is conducted at program initialization and generates the expected resource requirements per sortie for each type of aircraft on each mission type. These requirements include the expected manhours for each type of personnel, the expected utilization of each kind of AGE, part, and munitions, and the likelihood that any of the shop facilities will be required. These computations are carried out in subroutines RREQTS and REQTS1.

The second step of the procedure is to contrast, for each type of resource, the on-base assets with the per-sortie requirements. Taking the quotient as the constraint imposed on sorties by each type of

resource, the basic procedure is to determine the lower bound of all such constraints for each type of aircraft and each type of mission. The calculations are carried out daily at 1930 just before the sortie demand data are input and scheduled, and demand allocations may be required; the logic is in subroutine BASCAP (base capabilities) and is called from MANAGE.

The actual computations in subroutine BASCAP are somewhat more complicated than just outlined for several reasons. For the mission-dependent munitions, the calculation takes into account whatever lower priority combat loads could be loaded, as well as the preferred SCL; and for parts, the estimate is modified to account for the serviceable items that would be expected to be generated by parts repair. Furthermore, three different estimates are derived: The first estimate is made without regard to the number of aircraft on base; the second estimate introduces the additional constraint that no more than N × S sorties may be flown, where N is the number of aircraft of the type considered that do not have mission-critical "holes," and S is the maximum number of sorties that an aircraft could be flown between 0500 and ENDAY.

The third estimate provides an approximate accounting for other aircraft types that may be on base and that have common resource demands. The base's capability to generate sorties with each type of aircraft is determined by dividing the level of available assets by the aggregate demand of all aircraft types for each kind of resource (where the demands are weighted by the number of aircraft of each type).

These three estimates are stored in the CANFLY array for each base, each aircraft type, and each type of mission. In addition, the value of

the second estimate, for the mission with the highest estimated sortie potential, is stored in the SORCAP array for each base and aircraft type. It is the data in these arrays that provide the basis for the various aircraft management decisions during the ensuing 24 hour period.

2. PERIODIC REVIEW AND REALLOCATION OF RESOURCES

The available numbers of ground personnel, AGE and equipment, and serviceable aircraft parts may be reviewed periodically, and actions taken to redress serious imbalances that are noted. The nature and timing of these reviews are controlled by CTHEA and the user's choice for C4TM and C4INT. The first review occurs at the C4TM'th hour of the simulation and subsequent reviews are at intervals of C4INT hours. The delayed and imperfect status data reported to the theater manager by the theater communications system are used in these reviews.

The particular classes of resources reviewed at those times are dictated by the value of CTHEA as follows:

PERIODIC THEATER-WIDE RESOURCE CHECKS

CTHEA	PERSONNEL	AGE	PARTS
0	-	-	-
1	-	-	X
2	-	X	X
3	X	-	X
4	X	X	X
5	X	X	-
6	-	X	-
7	X	-	-

a. Ground Personnel

For each type of personnel, we first establish which base's staff has the largest and the smallest proportion of their nominal complement (adjusted for the actual aircraft on hand) and then send 20 percent of that type of personnel from the best staffed base to the worst, when certain conditions are met.

1. The gaining base has less than 75 percent of its nominal requirement.
2. The losing base has more than half its nominal requirement, and
3. The losing base has over twice as many staff members per aircraft as the gaining base.

The adjustment for the actual number of aircraft on hand consists of multiplying the bases' nominal "target" number for each type of ground personnel by the present number of aircraft, and dividing by the original number of aircraft.

b. AGE and Equipment

The logic applied to each type of AGE and equipment at each base is identical to that used for reallocating ground personnel.

c. Aircraft Parts

When parts are reviewed, a check is made on whether or not there are more parts of each type in the central supply (i.e., at the CIRF) than were specified to be held in reserve (by the user's initialization of the nominal or "target" level at the CIRF). If there are, a check is made as to which base has the greatest need and the parts are shipped,

one at a time, until the surplus is exhausted.

To determine which base is to receive a part, the operating bases are each checked and the total number of assets of that type of part on each base is determined by summing the serviceable items, those enroute, and the reparables when the base's repair shop is functioning. That number is then reduced by the number of aircraft needing that part on that base. At this point two alternate logics are used, depending upon whether the control variable STATE is zero or not. If it is zero, the asset count, when positive, is divided by the base's nominal allotment of that part (adjusted for the number of aircraft on base); if negative, the result is multiplied by nominal part requirement. If STATE is not zero, the asset count is further reduced by expected on-base demands for that part during the time that a part would need to be in transit; that estimate is based on the requirement-per-sortie data and the base's current sortie generation potential. For either value of STATE the final result is interpreted as the relative availability of that part type on that base, and a part is shipped to that base with the numerically lowest value of relative availability. This process is repeated until there are no parts of that type at the CIRF in excess of the specified reserve; the whole process is then repeated for the next type of part.

3. ACQUISITION OF SPARE PARTS

Whenever an aircraft "hole" is reported, that aircraft's operating base may, under certain conditions, request and, if other conditions are fulfilled obtain a spare part from another operating base or from the

theater's central supply. The procedures used are controlled by the value of CCIRF, which also controls the rules governing the disposition of newly repaired, and newly acquired parts at the CIRF. The procedures adopted are as follows:

CCIRF	BASE REQUESTS FOR PARTS	CIRF DISPOSAL POLICY
0	No response	Return to sender
1	Filled by first base fulfilling conditions	Return to sender
2	Filled by base best fulfilling conditions	Return to sender
3	Filled by CIRF when conditions permit; otherwise same as 1	Retained in stock
4	Filled by CIRF when conditions permit; otherwise same as 2	Retained in stock
5	Same as 3	Send to most needy base if in excess of req'd reserve
6	Same as 4	Same as 5
7	Filled by CIRF when conditions permit; otherwise CIRF directs lateral resupply	Same as 5

The procedures and conditions that govern the five different responses to a base request follow:

a. When CCIRF = 1, a simple mode of lateral resupply is simulated. Whenever a "hole" is reported, the bases that the user has specified (a maximum of four using the special version of Card Type #23), are checked one by one in numerical order, and the first base that fills the specified conditions ships a part to the requesting base. Those

conditions are, first, that the number of reparables minus the number of "holes" at the requesting base is less than the value of ORDER2, and, second, that either (i) the donating base has at least two serviceable parts, or (ii) the donating base's adjusted stock requirement--i.e., (Nominal Stock Level) × (Current Number of Aircraft) divided by (Nominal Number of Aircraft)--is less than one-quarter of a part. As the value of ORDER2 varies from a positive integer to zero to a negative integer, the policy for requesting lateral resupply can be varied from very liberal to very strict.

b. When CCIRF = 2, the procedures parallel those for CCIRF = 1, except that all bases are checked and the base with the largest number of serviceable parts is chosen; if the donating base has only one serviceable part, the current value of its nominal stock level must again be less than one-quarter of a part.

c. For values of CCIRF greater than 2, the first action taken by the ordering base is to check whether the theater's central supply as a part that may be shipped. If there is a serviceable part at the central supply point it is shipped if the requesting base fulfills the following condition: The sum of the ordering base's number of reparables, plus the number of serviceables already enroute from the central supply, minus the number of "holes" in aircraft at that base, must be less than the value of ORDER1. Again, a negative value of ORDER1 defines a strict lateral resupply policy, under which parts can be requested only when the number of outstanding "holes" exceeds the tangible assets by the specified (negative) level.

If a part is not shipped by the CIRF, the requesting base then attempts to obtain a part from an operating base by a lateral resupply action. For CCIRF = 3 and 5, the same procedure is used as when CCIRF = 1. For CCIRF = 4 and 6, the procedure is that used when CCIRF = 2.

d. When a part cannot be shipped by the CIRF, and CCIRF = 7, the central manager checks the other operating bases to determine which can best afford to ship a part to the requesting base. This check of the other bases is based on the status information as reported through the theater reporting system. To select the donor base the following ratio is computed for all other bases: (available parts plus enroute parts) divided by (the current level of the nominal base requirement). The base with the largest value for this ratio is directed to ship a part to the requesting base, if that value is greater than one-quarter. If it is not, but there are at least two serviceable parts at that base, one is shipped.

4. DISPOSITION OF NEWLY REPAIRED OR NEWLY ACQUIRED PARTS AT A CENTRAL SUPPLY POINT

As outlined at the beginning of the preceding subsection three options are available for disposing of newly acquired serviceable parts at the theater control supply point. For CCIRF = 0, 1, and 2, newly repaired parts are returned to the base where the reparable was generated; newly acquired parts are placed into the local stock. For CCIRF = 3 and 4 all such serviceables are placed into stock at the CIRF.

For CCIRF = 5, 6, and 7, any newly acquired part that is in excess of the central supply's stipulated reserve is shipped to the most needy base. That determination is made in the same manner outlined in conjunction with periodic resource reallocations; that is, it is sent to that base with lowest ratio of (serviceables + reparables + enroute - "holes") divided by the bases' current nominal requirement. These calculations are based upon the status information reported by the theater reporting system.

5. REPAIR PRIORITY DETERMINATION AT A CIRF

When broken parts must wait to be repaired at an operating base, their position in the appropriate shop's wait queue is based upon the local supply and demand, when the control variable ORDWT has been initialized as unity, as outlined in Section VII. At a centralized repair facility somewhat different procedures naturally must be followed when ORDWT = 1, since there is no local demand, as such. Interrupted repairs are given priority over waiting repairs when resources become available, on the assumption that if they were sufficiently important to have been started they should be finished. But when resources are available and no interrupted repairs are queued, the parts that have been waiting are checked to see which should receive attention. Actually the prioritization of waiting parts at a CIRF is a two-step process; one set of rules governs the order in which parts are placed into the wait queue and the second governs the criteria that must be satisfied when a part is withdrawn from the queue. The primary purpose of the first of these two procedures is to limit the processing required

for carrying out the second procedure.

Whenever a reparable concludes the administrative delay at a CIRF and must wait to be repaired, it is ordered in the wait queue by ascending values of the following quantity (i.e., items with low values receive priority over those with high values) when ORDWT = 1:

(Repair Time)/[(Aircraft with Holes)(Relative Importance)]

Thus parts that are important, needed, and can be repaired quickly receive priority. This parameter takes into account all aircraft types that use that particular type of part, and the importance[1] of that part to the missions that those types of aircraft can fly. If ORDWT is zero, the items are ordered FIFO (i.e., first-in first-out).

When personnel and/or AGE and equipment are released at the completion of another repair job, and when ORDWT = 1, two alternate sets of rules may be used for selecting the next part that will be repaired. The choice is made in subroutine CKCIRF (check CIRF) that is called whenever resources are released; the choice is controlled by the variable SHOPRY (shop priority). For either of the options, an empirical estimate is made of the demand outstanding for the first item in the queue, and, if the value of that estimate is greater than the threshold variable INDEX, the repair is initiated without checking any

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[1] The PRTCRT array is generated during initialization: For each part, each entry in this array contains, in packed form, a record of which aircraft types use that type of part, and which of that aircraft's missions require that part. The relative importance of a particular part, as used above, is defined as the sum of (number of mission types for which the part is required) divided by (number of mission types that can be flown) for the several types of aircraft using the part.

further. If it is not, the next part is checked, etc. If the value for none of the parts exceeds the threshold, the one with the highest value is initiated.

The manner in which the demand outstanding for a given part is estimated is controlled by SHOPRY. When SHOPRY = 1 the demand is estimated as the product of the number of aircraft that require the part, times the part's importance, where "importance" is as defined above.

When SHOPRY = 2, the estimate of demand takes into account both the current backlog of repairs and the expected future demands for parts based on the present pattern of sortie demands. This is done by expressing demand as proportional to the sum of (1) a fraction of the existing number of "holes", and (2) the number of "critical holes" that would be expected to develop over the average shipping time if the current sortie demands continued and were met. The fraction of the existing "holes" included in this calculation is:

F = (the current number of sorties demanded for which the part is essential)/(the current number of sorties demanded of aircraft that use the part),

which is determined by summing the demand for sorties across the various types of missions and aircraft. The expected number of critical holes that would be generated is estimated as

E = (the current number of sorties demanded for which the part is essential)/(the mean number of sorties before failure of the part)

Thus the overall demand, or relative importance, of repairing any particular part is taken to be

DEMAND = 10 × [F × (existing "holes") + S × E]

where S is average shipment time in days, and the factor 10 has been introduced simply to maintain distinctions among the integer values of the demands. As with the other option, repairs are initiated for any part whose "demand" exceeds the value of the variable INDEX; if no value is that large, repairs are initiated on the part with the largest value of demand.

XII. DATA INPUT

The first step of the input process is to zero out all storage arrays and define their dimensions; this is the primary function of subroutine INIT. That subroutine also contains a variety of material that will assist the programmer in accomplishing whatever redimensioning is required to tailor TSAR to his special requirements. These materials include the 20 primary sets of named COMMON, a complete list of the arrays that are found in COMMON, data clarifying which array dimensions may be modified, and extensive comments to explain how such changes should be accomplished. Many of these materials may also be found in Volumes II and III. Whenever TSAR's array structure is redimensioned, special care should be taken to assure that the loops used in subroutine INIT to zero out the corresponding space span the correct range. The auxiliary program SIZE.TSAR.STORAGE may be used to help make these changes.

The second step in the input process is to read the input data provided by Card Types #1 through #49 using subroutine INPUT, INPUTA, INPUTB and INPUTC. The definitions, formats, and procedures for entering these data are outlined at length in Section XIX in Volume II. The user has considerable latitude as to what is to be included; many portions of TSAR may be inactivated simply by omitting a card or by providing a null entry for certain data.

The input process has several built-in checks (actuated when VERIFY > 0), but the user should adhere precisely to the instructions; when VERIFY = 3, each input card is screened by subroutine TESTER, which has been designed to catch a variety of common errors.

Subroutine INPUT calls on subroutine INPUTC to read airbase attack data and airbase damage data and to organize the attack times in a heap. The INPUTC subroutine is designed so that these data may either be input directly with the TSAR data deck or read from disk, where they have been stored by the companion model TSARINA, which computes the required damage data from a description of the attacks and the location of resources among the various airbase facilities.

In addition to simply storing data, subroutine INPUT, assisted by subroutine WRAPUP, also arranges resource shipments from CONUS in a time-ordered queue, computes the entries for the SHPTSK (shop tasks) array, and uses subroutine AVGTME (average times) to compute the average time that each aircraft maintenance shop can be expected to spend on on-equipment tasks and off-equipment repair jobs for each type of aircraft, when base resources are unlimited. These estimates take into account the likelihood that the different tasks will arise, parts will be broken, and the parts will not be condemned or shipped to another base for repair.

In addition, subroutine WRAPUP uses subroutine RREQTS to compute the expected requirements for personnel, equipment, parts, munitions, and shop facilities for each type of mission and each type of aircraft when the control variable STATE has been initialized to a value greater than zero. These estimates are used subsequently in subroutine BASCAP (base capabilities) to provide daily projections of each base's sortie generation capabilities.

When the user has elected to let TSAR initialize the parts data and the parts pipeline to the depot, as outlined in subsection VII-1, subroutine COMPRT (compute parts) is called next by WRAPUP. When this option is chosen the user must first have stipulated certain base characteristics and the NRTS policies for each part and each type of base (using special versions of the Card Type #23). Subroutine COMPRT manages subroutine IPARTS and IPART2, which compute the total numbers of each type of part for each type of base; POS plus BLSS are derived for in-place units and a WRSK kit is created for units that are deployed to the theater. Listings of the results of these computations and of the pipeline contents are controlled by PPRINT.

The user has two options for recording the input data: simply to list input data as it is entered, the user places a "1" in column N of the first input card, if Card Type #N is to be listed. The other option lists the data after they are stored and after the various special initialization actions have been carried out; this option is requested with the special card that precedes the sortie demand data; again a "1" is placed in Column N if the data read with Card Type #N is to be reproduced. The subroutine INLIST and the support routines LIST1, LIST2, LIST3, LIST4, and LIST5 respond to these demands. The user should note that the data are printed directly from storage and that they frequently have been modified or "packed" differently than when they were input. The definitions provided for each array in Appendix B will permit the user to interpret these listings.

The last steps in the input procedure are managed with subroutines INITIZ and TRIALS. The pointers identifying the available space in the several dynamic storage arrays are initialized in INITIZ. The last step

in subroutine INITIZ is to list the status of personnel substitutability at each airbase. Initialization is completed in subroutine TRIALS; when the control variable STATE has been initialized to a value greater than zero, subroutine BASCAP is called to generate the initial projection of each base's sortie generation capabilities. These approximate sortie projections are derived by comparing the average resource demands for each type of mission and each type of aircraft with the available quantities of those resources at each base, as outlined in Section IX-1. These projections are subsequently updated each evening at 1930 and are used with a variety of algorithms concerned with managing aircraft assignments and transferring aircraft from base to base.

If theater resource reports are to be transmitted during the simulation, TRIALS next calls subroutine STATUS to initialize the theater manager's data base with up-to-date and complete information regarding the resources that will be managed. The intra-theater shipping schedule queue is organized next.

The next step in TRIALS is to input the initial set of sortie demand data. This is done by calling the entry point DAYONE in subroutine READFT (read flight data). As explained at greater length in Section VIII, these data can be replaced or modified each day at 2000 or, if the flights are periodic, they may be used to control the demand for sorties for several days or throughout the simulation. Finally, the heap in the array PERIOD (periodic and scheduled tasks) is initialized in subroutine MANAGE (using entry point MANAG).

The input procedure up to this point has been primarily concerned with acquiring the data that describe the various tasks and the initial

resource levels and schedules, and with initializing various queues and heaps. The initial status of the aircraft and the maintenance shops is established with Card Types #41 and #42, and, when parts are initialized automatically, NORS aircraft may be designated to provide sufficient parts to stock the pipelines. If only Card Type #41 is used it is presumed that in the situation that is being simulated, there has been an opportunity to work off all unscheduled maintenance tasks except for NORS aircraft, and to upload the aircraft for some type of mission at the beginning of the simulation. Similarly the parts stockage generation option presumes that all on-base parts are serviceable. Thus the various shops are inactive and no jobs have been interrupted or are waiting. To be consistent, the available ground personnel and equipment should have been set to their maximum values.

To reflect a situation in which aircraft maintenance tasks remain to be completed and various parts are being repaired or are waiting to be repaired, subroutine ZSHOPS is called by subroutine TRIALS. This modification of the initial conditions is controlled by Card Type #42, where the aircraft maintenance that is outstanding is expressed by a three-part distribution for each type of aircraft at each base. Thus one might specify that 20 percent of aircraft type #2 at base #3 has two tasks outstanding, 30 percent have three tasks, and 10 percent have five tasks. Subroutine ZSHOPS selects the required tasks at random, consistent with their nominal probability of occurrence, and computes the time remaining as a random fraction of the normal task time. If parts repair jobs are specified on Card Type #42, the appropriate numbers are selected and placed in the administrative delay queue or in

an in-process status by an equivalent random process.

The default air crew status (established in subroutine INPUTA) is that all air crews will be available for assignment at any time after 2:00 AM on the first day. If some pilots must receive more (or less) rest, the appropriate elements of PILOT(3,I) would need to be reset to the proper time (in TSAR time units).

When all phases of the initialization process are completed, program execution is terminated if VERIFY was set to 2 or more, either by the user or in response to input errors that TSAR detected.

XIII. SIMULATION CONTROL

The MAIN routine initiates and concludes the simulation but delegates the control of the three main phases--input, simulation, and output--to subordinate routines. Input has been discussed, and printout of the final results is controlled by subroutine OUTPUT. Control for the simulation proper is passed first to subroutine TRIALS, which is responsible for the last portions of the initialization process and for running the simulation the designated number of trials. TRIALS manages the storage of the initial conditions for the first trial, for regenerating zero-time shop activities, and, when spares stocks are computed internally, for recomputing the initial spares for each trial. Control is passed by TRIALS to subroutine MANAGE, which exercises primary control throughout each trial of the simulation.

The basic task performed by subroutine MANAGE is to examine the earliest event that will occur in each of eight separate groups of events and to determine which of these eight is to occur next. Simulated time is then advanced to that time, and control is transferred to the appropriate subroutine for processing that event.

If the next event in each of two or more of these eight groups of events is to occur at the same time, the first event examined is processed first. The order in which the groups are examined is:

1. Completion of civil engineering reconstruction jobs
2. Completion of on-equipment aircraft maintenance tasks
3. Completion of aircraft parts repair jobs

4. Periodic and user-scheduled events
5. Completion of aircraft delays (dead times)
6. Aircraft sortie launch events
7. Completion of munitions assembly jobs
8. Arrival of resupply shipments

This order has been established primarily with a view minimizing unnecessary processing. Thus shop reconstruction is checked before maintenance personnel are released, so that parts repairs that are awaiting initiation would not need to be checked twice. And on-equipment tasks and aircraft delays are completed before flights are checked so that aircraft that are becoming available for launch are so designated at launch time.

Control is transferred to subroutine BSEREP, RUNAC, RUNSHP, FLIGHT, DOBILD, and DOSHIP for the first, second, third, sixth, seventh, and eighth groups, respectively. For the fourth and fifth groups the nature of the event or delay determines which subroutine takes control; subroutine MANAGE transfers control to the appropriate location.

Many of the user-defined management control variables may be changed during the simulation. The time at which any such change is to occur may be specified in the input data, or may be selected endogenously, thus providing a form of dynamic adaptive control. Subroutines ADAPT and MODIFY provide for the management of the user-supplied logic that controls such adaptive behavior.

When processing has been completed by the subordinate routine(s), control is returned to subroutine MANAGE and the next earliest event is selected. The entire simulation proceeds in this manner until the

user-stipulated simulation length is exceeded, at which time MANAGE returns control to TRIALS to print the trial results and to initiate the next trial, or to print the overall results of the several trials.

XIV. SUPPORT SERVICES

Fifteen subroutines and 11 minor subroutines and functions support the main simulation. Each performs one or more specific functions and many are called upon from a variety of different locations. The functioning of each of these support routines is described at least briefly in this section. These discussions are ordered alphabetically; the subroutines discussed include:

BREAK	Computes break-rate modifiers for on-equipment tasks when VBREAK is unity
CHECK	Checks on outstanding demands for newly available resources that have been released from aircraft maintenance tasks and parts repair jobs
ENDAC	Eliminates all records associated with an on-base aircraft
FTIME	Generates time requirements for civil engineering jobs
HEAP	Enters and removes items from a heap
INTRUP	Enters and removes time-ordered items from the interrupted task array
KILLAC	Eliminates all records for an aircraft that is lost in combat
LOSSES	Determines the specific number of items lost
NORRPT	Enters and removes records of aircraft "holes" from the NORQ array
REDPEG	Reduces or increases the number of ground personnel and reorganizes the shift structure
RESET	Resets simulation time for a continuous simulation of NTRIAL × SIMLTH days duration when EXTEND = 1
SHIFT	Adjusts the size and activity of the work force when shifts are changed
STRTSK	Stores and retrieves required and deferred on-equipment tasks
TTIME	Generates time requirements for aircraft maintenance and theater communication delays
WAIT	Enters and removes time-ordered items from the waiting-task array

The other 11 service items are summarized briefly at the end of this section.

Subroutine BREAK

This subroutine is used when VBREAK is initialized to unity to modify the probabilities with which on-equipment tasks are required as a function of achieved sortie rate. Called at the end of each day, this subroutine computes the sortie rate achieved during the preceding day for each type of aircraft; the estimate is given by the total sorties flown by each aircraft type and the total number of such aircraft surviving in the theater. The appropriate break-rate modifier is then computed separately for each shop and each aircraft type on the assumption that the nominal break-rate applies for a sortie rate of one per day, and that the actual break-rate falls linearly for each additional sortie-per-day by the percentage specified with Card Type #44. The resultant value is stored in the second element of the TSKPR array.

Subroutine CHECK

This subroutine is used to check on resource demands that may be outstanding and is called whenever resources are released from a previous event or are delivered to a base. The five sources for such demands are interrupted, waiting, and deferred on-equipment aircraft maintenance tasks and interrupted and waiting parts repair jobs. To reduce processing somewhat, the call to this subroutine may specify a shop number, an aircraft, a part, a type of personnel, a type of equipment, or any combination. In the subsequent search among outstanding demands no attempt is made to initiate tasks that do not require the resource specified.

The search is ordered so as to examine on-equipment tasks before parts repair jobs; in each case, interrupted items are examined before

those that are waiting. At night (after ENDAY), deferred tasks are checked after repairs have been checked. All five queues are searched when a shop or a type of ground personnel is specified. If an equipment type is specified, only on-equipment tasks that are waiting (and, at night, deferred) are checked. When an aircraft is specified, only on-equipment tasks are examined. When an LRU is specified, the aircraft waiting for that part are examined to select the one with the fewest holes, and if two or more have the same number of holes, the aircraft with the earliest projected ready-to-fly time is selected. When the part specified is an LRU, only jobs waiting for repair are examined.

For the shops that may lend personnel or equipment to other shops, subroutine CHECK next checks the shops that are listed in a TSAR-generated list of borrowing shops to see whether the newly released personnel or equipment are needed either for on-equipment or for off-equipment jobs. If so, the resource is lent to the shop that is found to require it.

Subroutine ENDAC

This subroutine is used only when an aircraft has been damaged or destroyed by an enemy air base attack. It is called from subroutine BOMB after that subroutine has appropriately decremented the personnel, equipment, and parts associated with the aircraft at the time of the attack.

For damaged aircraft ENDAC is used to eliminate any flight assignments; if an aircraft has been destroyed, ENDAC then removes it from the aircraft delay queue (when appropriate), and removes all references to required, interrupted, or waiting tasks. All ongoing

tasks are then stopped and the surviving personnel and AGE are released for other jobs. No times are recorded for these tasks. The last step is to call subroutine KILLAC in order to erase any deferred task records, to eliminate the aircraft from the base inventory, and to order a replacement aircraft, as appropriate.

Function FTIME

This special function provides the user substantial flexibility for specifying how the required time for civil engineering jobs vary for different types of jobs and different levels of damage. In basic terms, the formulation consists of a delay, or start-up time, plus a damage-dependent reconstruction time. For each type of civil engineering job, the user specifies the time (t) required to repair a "unit-of-damage" and indicates how the total time (T) will vary with the total number of units of damage (D) by entering a coded number (C) for the functional relationship.

This subroutine uses those data to estimate total time as follows:

$$T = \text{Delay} + t \times D^b$$

where

$$\text{Delay} = f(B)$$

$$b = g(P)$$

and, since $C = 12 \times P + (B - 1)$,

$$P = C/12 \qquad \text{the largest integer multiple of 12 in C}$$

$$B = C - 12 \times P$$

The data tabled in FTIME for f and g provide 12 values for the delay (0,1,2,3,4,6,8,12,18,24,36, and 48 hours) and 7 values for 'b' (.5,.75, .9, 1.0, 1.1, 1.25, and 1.5). To specify a time proportional to the total damage, without any initial delay, C would be 48--i.e., P = 4, B = 1, so that b = 1.0 and Delay = 0.

Subroutine HEAP

When it is not necessary that timed events be ordered, but only that the earliest event be readily located, a data collection that has been called a "heap" permits more efficient processing. On the average only two positions need be checked when a new event is entered into a heap.

This subroutine has four entry points, one to enter an item (INHEAP), one to remove the item with the lowest valued time (OUTHEP), a third to extract an item (EXHEAP) from within the heap, and a fourth to modify the time for an item in the heap (MODHEP). To extract an item from the heap, or to modify an item, it is necessary to know which column it occupies in the parent array, if it is to be found readily; but when these actions are required before an event has become the one with the earliest time, that information logically is known.

The size of the calling array is a variable and the number of entries in that array may be fixed or variable. This subroutine operates on three rows of whatever storage array is specified in the calling statement. The time of the event is in the first row, a pointer to the event's position in the heap is in the second, and a pointer back to the event from its position in the heap is in the third row.

One peculiar property of this data structure should be noted: If several events are entered that have the identical time associated with

each of them, they will not be removed in the same order in which they were entered.

Subroutine INTRUP

Aircraft on-equipment tasks and parts repair jobs that have been interrupted are queued in the INTTSK array. Each shop on each base stores a pointer to the first and the last of its interrupted tasks and its interrupted repairs in the array SHOPS. Whenever resources are available to start an interrupted activity the first item in these queues is the first to be examined. If the user wishes priority to be given to the item the has been in the queue the longest, the control variable ORDIT is initialized to zero and the queue is managed locally in the main routines.

If the user wishes to have the events ordered such that the one with the lowest value of a variable called TIME is first, ORDIT is initialized to unity, and subroutine INTRUP is called to manage the queue. The value of the variable TIME need not be a time, per se, and, as discussed elsewhere, differing events are queued in accordance with differing definitions for TIME.

This subroutine has separate entry points for entering an item (ININT) and for removing an item (OUTINT). The code is written so that any item may be removed, not only the one that is first in the queue. Three rows of the INTTSK array are involved in queue management; the value of the variable TIME is stored in the seventh row, and pointers to later and to earlier items are in the fifth and sixth rows respectively.

Subroutine KILLAC

This subroutine is used whenever an aircraft is lost in combat, and it also completes the work begun in ENDAC when an aircraft is destroyed on base. The two basic functions performed by this subroutine are to erase any reference to tasks that may have been deferred on the aircraft and to eliminate the aircraft from the base inventory.

Subroutine LOSSES

This subroutine generates the specific number of items that are lost when N items suffer a loss probability of P. If the control variable NONUNI is zero, the value returned for one item is determined by comparing a random number with P; for more than one item the value returned is that integer closest to the expected losses--i.e., N × P. If the control variable NONUNI is unity, the value returned is a sample drawn from the binomial distribution (determined by comparing N random numbers with the value P).

Subroutine NORRPT

Whenever a part has been removed from an aircraft and has not been replaced immediately, or whenever a part on an aircraft has been found to be defective but has not yet been removed, a record is made of the particular aircraft and part. The data on these reports, or "holes", are stored in array NORQ using subroutine NORRPT.

Whenever an entry is made in NORQ (using entry RPTNOR) this subroutine first adjusts the number of aircraft on the base that are missing a part and then adjusts the count of the "holes" in that aircraft. If the rules for intra-theater resource transfer permit, an order may be issued (by a call to subroutine CONTRL) to ship a part of

the required type to the base that reported the "hole." The discussion of subroutine CONTRL outlines the rules that are followed in different circumstances (see Section XI).

The last step is to place the aircraft number in the NORQ queue that contains the numbers of those aircraft assigned to that base and missing that part. The aircraft number is ordered in the queue by the amount of time remaining until the aircraft would have been ready to fly if the part had been available; the aircraft with the least time is first. For subroutine NORRPT to manage these queues, the array NORQ stores the aircraft number, the time remaining, and a pointer to the next report in the queue. The fourth element of the PARTS array (PARTS(PART, 4, BASE)) contains the pointer to the position in the NORQ array of the first aircraft that requires that type of part.

Whenever the aircraft "hole" has been filled, this subroutine is called through entry REDNOR to take the record out of the queue in NORQ. This is done after the tallies noted earlier are updated.

Subroutine REDPEO

This subroutine is used to reduce the number of ground personnel on a base when some are shipped to another base and to reorganize the number that remain after an airbase attack. Subroutine SHPRES calls in the first instance and subroutine BOMB in the second. Calls to this subroutine prescribe the type (PEOP) and the number (NUM) of personnel to be withdrawn; NUM = 0 when the survivors of an air attack are to be reallocated to the day and night shifts. Distinct procedures are used for aircraft maintenance personnel and for civil engineering personnel.

The first step in this subroutine is to identify whether personnel of the designated type are assigned to two or more on-base organizations (the ALTPEO array provides the necessary data on the equivalent types of personnel). If they are, the personnel are redistributed among the several organizations in the proportions implied by the "target" force levels. The next step is to establish what numbers will be on the day and night shifts after reorganization. The new shifts are sized in the same proportions as the "target" force levels, except that no shift is allowed to be smaller than the "minimum shift size" entered with Card Type #17.

If some personnel at work during the present shift must be released, parts repairs are interrupted first; if more personnel are required, aircraft maintenance tasks are interrupted. If more people have been directed to be transferred than can be found, the number to be transferred is reduced accordingly; this situation can arise if personnel are being used in other than their "parent" shop (where they cannot be located readily).

The procedures for the civil engineering personnel are comparable except that they are all in a single organization and the choice of tasks to be interrupted is based on the facility priority list (Card Type #39); personnel are released from the lowest priority task first. When a civil engineering task is interrupted the work remaining to be done (i.e., the current damage level) is estimated on the assumption that the remaining work is the same fraction of the total job as the remaining time is of the total time. The quantities of unused building materials are estimated in the same manner and they are returned to stock.

Subroutine RESET

When the control variable EXTEND is initialized to unity, the simulation may be extended to an indefinite length and is not restricted to 65 days. This is done by resetting the various time values in the simulation data base at the end of each trial, but without reinitializing any of the resource status values; thus the second trial is just an extension of the first etc. This subroutine performs all the necessary time adjustments when called by subroutine TRIALS.

Subroutine SHIFT

This subroutine is called at two hour intervals by subroutine MANAGE and changes the size of the on-duty work force for the personnel assigned to whichever work-centers (shops) have a shift change at that time. Both the day and the night shifts are assumed to be 12 hours in length. Shifts that begin between midnight and 10:00 AM, inclusive, are designated the "day" shift. Using Card Type #19, the shift schedule is prescribed independently for each shop. The work schedules are the same on all bases for shops of like number; however, the number of personnel on the different shifts is controlled independently for the different bases using Card Type #21. Only aircraft maintenance personnel are treated in this subroutine; civil engineering personnel are assumed to pursue reconstruction tasks at a steady rate and are organized into shifts of equal size.

The basic function of this subroutine is to check whether more people are currently engaged than will be available on the next shift,

and if so, to interrupt a sufficient number of activities that the required number of personnel may be released, or, if more people will be on duty, to attempt to assign the extra personnel to interrupted or waiting activities. The complications arise from personnel that may (1) be allowed to work a specified amount of overtime if they can complete their task within that time, or if they are engaged on an aircraft that has been scheduled for a late takeoff; and (2) have been lent to another shop and will not be found when their parent shop is checked.

The first step taken when a shop changes shifts is to reset a flag and zero a counter in the sixth and seventh positions of the PEOPLE array. Then, for each shop, each parts repair job and each aircraft maintenance task is checked. At the first encounter with an as yet unchecked type of personnel, the flag is set to one and the net change in shift size is established. If the new shift is sufficient to handle all ongoing repairs and aircraft tasks, the flag is set to two, and the next activity is checked for any different personnel types that may be at work. If the follow-on shift cannot handle the current work load, parts repairs and on-equipment tasks are interrupted (in that order) until a sufficient number are released, at which point their flag is set to two. The most recently initiated parts repairs or on-equipment tasks are interrupted first. The counter in the seventh position in PEOPLE is used to maintain a record of the number of personnel that remain to be released.

If the personnel on a particular activity can finish their task within the allowed overtime period (for this decision it is presumed that the exact completion time is known), or if they are working on an

aircraft that is scheduled for a late takeoff, they are allowed to continue; they are credited to the required reduction, and subtracted from the "available" personnel for the subsequent shift. Thus at the beginning of a shift the number of personnel available can be a negative number equal to number of personnel that are working overtime; as each group is released, the "available" personnel remains at zero or less until fewer than the designated number on the next shift remain assigned.

When personnel have been lent to another shop that may have its shift change at a different time, the flag and the counter are still operative; when the various activities are checked and the "borrowed" personnel are noted, they will be released if their flag value is zero or one. *Otherwise, the activity continues; in effect, members of the* new shift take over for those on the previous shift.

To avoid overlooking personnel assigned to shops that have no activity underway at the time the shift is changed, ground personnel are next checked type by type, and the PEOPLE data are modified as appropriate, when their parent shop has a scheduled shift change and the personnel flag is still zero.

For shops that have had a net increase in work force (measured by the counter REMJ), subroutine CHECK is called to start any outstanding jobs.

The only exceptions to the preceeding description occurs for the "flight line" shop--shop #25--and the shops associated with the preflight tasks--reconfiguration, weapons loading, and refueling (shops 27, 28 and 29, respectively). Personnel attached to those shops who

must be released are required to complete their current task, without regard to allowable overtime. This is done because such tasks tend to be fairly short and because it seemed likely that such critical tasks would be completed in wartime.

Subroutine STRTSK

This subroutine manages the storage of unscheduled on-equipment maintenance tasks in the RQDTSK and DEFTSK arrays. At the time an aircraft lands and the unscheduled tasks are identified in subroutine PSTFLT, a tentative mission is selected for the next flight and the tasks are separated into those that are required and those that may be deferred. Separate entry points are provided to store (STTASK) and to remove (REMTSK) a task, and a flag in the calling statement identifies the array to which the task belongs.

Each array is used to maintain an ordered set of tasks for each aircraft; two pointers in the ACN array determine the positions in the RQDTSK and DEFTSK arrays where the first tasks are stored for each aircraft. The tasks are ordered as they are identified, and for the required tasks the sequential shop structure that is defined with Card Type #29 is preserved by entering the minus value of the first task identified for each group of shops whose work may be pursued simultaneously. The end of each set of tasks for an aircraft is identified by a zero entry in the task number position.

Function TTIME

This function selects the "true" time for a job on the basis of a mean task time and a time distribution that are specified in the calling

statement. For both on-equipment and off-equipment aircraft maintenance tasks, the user is restricted to the use of nine distinct distributions; for intra-theater transportation and communication delays, up to 15 distributions may be specified (i.e., six additional distributions).

Twenty-five data points are stored in the local DIST arrays to represent each distribution. Several log-normal and uniform distributions with different variance to mean ratios are available currently in FTIME in TSAR and these could be changed easily to satisfy special user requirements. These data are interpreted as 1000 times the ratio of the true value to the mean value. The entry selected is determined by the draw of a random number between 1 and 25. The true time value is returned in TSAR time units (multiples of three minutes).

Provisions exist so that the user may add delays or speed-up factors to the true time calculation. The nominal task times generated in TTIME are modified by use of several control variables to represent such efforts to shorten and otherwise expedite jobs. If the mean time and the random variate are designated as TM and F, the actual task time is generated as:

$$\text{HURRY} \times F(\text{TM} - \text{REDUCE}) - \text{SAVE}$$

where the variables HURRY, REDUCE, and SAVE may be specified separately at each base for on-equipment tasks, preflight tasks, parts repair jobs, munitions assembly jobs, and civil engineering tasks (see Card Type #17/2).

Subroutine WAIT

This subroutine manages the on-equipment and off-equipment jobs that must wait and are stored in the WAITSK array, in the same manner that subroutine INTRUP manages interrupted activities. Each shop on each base has a pointer to the first and the last on-equipment task and to the first and the last parts repair job that is waiting for action by that shop.

This subroutine is used only when the user wishes to have activities ordered in their queues by the value of the parameter TIME; to be so ordered, the control variable ORDWT is initialized to unity. The items are ordered such that the one with the lowest value of TIME is first. And as with the INTRUP subroutine, the value for the TIME variable need not be a time, per se; the specific definitions in use are explained in connection with the calling routines.

The mechanics of this subroutine are identical to those in INTRUP, except that the queues are maintained in the 7th, 8th, and 9th positions of the WAITSK array.

ADDITIONAL SERVICES

There are 11 additional services; five are used in conjunction with the INLIST subroutine for formatting the listing of input data (i.e., LIST1 thru LIST5). Four of the services interpret TSAR time to provide the time of day in TSAR time units, or hours and minutes, and the day and the hour (TOD, HRMIN, DAY, and DATE). The last two functions control the time horizon for projecting aircraft supply and demand (function THF) and the length of the time intervals used in that process (function TU). The user may specify these factors with his entries on Card Type #4/2, or use the encoded default values. As currently coded,

the default values for the the time horizon are 8 hours between 4 AM and 4 PM, 12 hours from midnight to 4 AM; 16 hours from 8 PM till midnight, and 20 hours from 4 PM to 8 PM; the 16 time intervals are defined by the function TU.

XV. OUTPUT

In a simulation that involves multiple trials and as wide a variety of activities as TSAR, a great abundance of data might be reported. The output options that are provided with TSAR permit the user to examine a substantial portion of what I judged to be the more relevant results, but all possible outputs certainly are not available. For the additional, more specialized kinds of results that some users may find necessary for their particular problems, custom additions should be appended at the time they are required. Otherwise, the costs in time and dollars for storing the data, and the space for displaying them, would have to be borne by all users.

The current output options are controlled by the variables PRINT, STATFQ, CUMSTA, PPRINT, and SCROLL. Input information that precede the simulation results in the printed output are discussed in Section XII. (The various debugging statements and outputs controlled by the variable TEST will not be discussed in this section.) For the individual trials PRINT controls the data printed that relates to the numbers of flights and sorties flown and the numbers of maintenance tasks accomplished. STATFQ controls the collection and display frequency of shop performance statistics, including statistical data on the resource constraints that cause on-aircraft maintenance delays; these statistical data may be obtained separately for each trial, or the results may be aggregated over all trials, depending upon whether CUMSTA is 0 or 1. PPRINT controls the display of the numbers of serviceable and reparable spare parts at each base, both at initialization and whenever shop statistics are printed.

SCROLL provides the user an opportunity to observe the behavior of aircraft in some detail. When SCROLL is used, a record of the daily activities for each of up to 24 consecutively numbered aircraft is listed at the end of each day for the number of days specified. The number of the first of the aircraft is #1, unless otherwise specified. The four numbers listed immediately following the aircraft number are the number of sorties initiated that day, the number of the base the aircraft is assigned to, a coded number summarizing the aircraft's maintenance status, and the current number of "holes" in the aircraft. Following these data, the times for the beginning and end of each flight and for each on-equipment task are listed, along with a description of the completed activities.

In addition to these various data that may be obtained for each trial, the final results also include a day-by-day record of the average number of sorties flown, and the standard deviation thereof, for each mission and for each base, when more than one trial is run. Other results printed for multiple trials include the averages, by day, of the numbers of aircraft that are possessed (overall and by base), the aircraft that have been lost overall, the aircraft that have been damaged (overall), the aircraft still damaged (by base), the aircraft that are NMCS (overall and by base), and the cumulative totals of the NMCS aircraft-hours (overall and by base).

OUTPUT CONTROLLED BY THE VARIABLE PRINT

The data provided for each trial for a particular value of the variable PRINT includes all items down to and including those listed for that value in Table 3.

OUTPUT CONTROLLED BY THE VARIABLE STATFQ

When STATFQ is initialized to a value greater than zero, data on the duration of aircraft maintenance tasks, parts repair jobs, equipment

Table 3

OUTPUT DATA CONTROLLED BY THE VARIABLE PRINT

PRINT	OUTPUT DATA
-1	EOT: Storage array status if any overflows occur in one or more of the 18 dynamic storage arrays.
0	EOT: Cumulative flights and sorties flown, demanded, and the percentage of sorties flown of those demanded; totals for each base and each mission.[a] EOT: Cumulative on-equipment tasks, parts and equipment repairs by base and by shop. EOT: Readiness indices[b] and cumulative hours NMCS at each base.
1	EOT: Sorties flown, demanded and the percent of those demanded by base and mission, ordered by priority. EOD: Aircraft possessed, lost, damaged, fillers, reserves, and transferred. EOD: Sorties and damaged aircraft by base. EOT: Daily reports listed for PRINT = 2.
2	EOD: Sorties flown, demanded, and the percent of those demanded that were flown by base and mission. EOD: On-equipment and off-equipment tasks completed during the day by base and by shop. EOD: Current supply of munitions by type. EOD: Numbers of tasks and repairs being processed, and the numbers of tasks waiting by base and by shop. (also listed at noon if PRINT = 3) EOD: Status of AIS and dynamic storage, and spares shipments. EOT: Remaining supplies of munitions and spares. Number of NMCS aircraft by base every six hours. Numbers of aircraft possessed, damaged, and with one or more "holes" by base, at three hour intervals. Notice of the initiation of runway or taxiway repair.
3	EOD: Flights flown and demanded by mission and base. EOD: Numbers of sorties launched each hour at each airbase. EOD: Numbers of repairs waiting, tasks and repairs interrupted. EOD: Cumulative manhours on aircraft tasks, parts, and equipment repairs by shop and by base. Current supply of spare parts at each base every six hours. Notice of initiation of facility repairs.
4	The numbers of interrupted tasks and repairs at noon. Available munitions by type every six hours. Notice of completion of facility repairs.
5	Hourly listing of the number of aircraft waiting at each shop on each base.
6	Numbers of personnel, equipment, and parts for restricted types[c] of these resources are listed at noon for each base.

EOT = End of trial
EOD = End of day

[a]Sortie data are available by base, aircraft type, mission and priority.

[b]The readiness indices provide a cumulative measure of how quickly aircraft were prepared for flight. The index is the average percentage of each base's aircraft that were ready to fly within 2, 4, 6, and 8 hours after the previous sortie.

[c]The data include PEOPLE(I,3,BASE) for I = 1-20 and 27-30; AGESTK(I,2,BASE) for I = 1, 24; PARTS(I,J,BASE) for I = 1-24 and J = 1 and 2.

repair jobs, and aircraft maintenance delays are stored using the subroutine TIMES. These data are printed at the end of each STATFQ days, at the end of each trial, and at the end of the simulation by calling subroutine DELAYS from subroutine OUTPUT. In each case, the results presented are based on the cumulative data to that point in the simulation if CUMSTA is 1; if CUMSTA is zero the results are cumulated independently for each trial. The results at the end of each trial also include the delay data for those activities that are still waiting at that time, on the assumption that all delays end at that time.

The first set of results present the number of activities, and the average length and standard deviation of the time that they required, for on-equipment tasks, for off-equipment jobs, and for equipment repair jobs at each shop on each base.

The standard time, or resource unconstrained time, as calculated during the input process in subroutine AVGTME is also listed for the on-equipment and off-equipment activities; the values computed in AVGTME for the various aircraft types are weighted in the output by the numbers of sorties flown by the various aircraft types at each base.

The second set of data provide a count of the ready aircraft that were canceled by a crew shortage and a count of the additional numbers of crews that would have been needed to satisfy the minimum flight requirements.

The last set of data provide a statistical summary of the causes and the duration of aircraft maintenance delays. For each base, for each of the other nine classes of resources, and for each individual resource type that caused an on-equipment task to be delayed, the

results include the number of such delays and the average value and standard deviation of their duration. If any of the aircraft have "holes" at the time of the report, the number of holes is listed with the parts data for each base.

Data of the several types controlled by STATFQ are listed only when there are results to be reported; null data are suppressed.

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